THE SHIELDED FOUR-ELECTRODE VALVE

The Shielded Four-Electrode Valve

Theory and Practice

By

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PREFACE

In presenting the public with this book on the shielded four-electrode valve, otherwise the screened-grid valve, I may say that during the past three years I have had considerable experience in the handling of valves of this type and have been able to draw upon that experience in explaining in these pages the more important points in the theory and practice relating to what I believe to be an unrivalled method of high-frequency amplification.

There are many minor pitfalls in the path of the experimenter, and it is my hope that with the help of what is here written he may be prevented from falling into any of them.

Four-electrode valve history, particularly that dealing with the method of shielding the grid, is at the moment rather vague, and apart from noting that the general idea of shielding the grid from the plate dates back to at least 1919, I shall refer only to Dr. Hull's wonderful series of papers in the *Physical Review* (1916) in which he describes his own type of shielded valve for high-frequency amplification and discusses at length the possibilities of its use.

The shielding idea has cropped up many times

during recent years, but, personally, I did not take up the subject seriously until early in 1925, during which year I carried out a series of experiments with cascade amplifiers, as described by me in a contemporary publication (February, 1926). Since that date, however, I have studied the whole subject very carefully, and this book represents to some extent the result of these studies.

The issue of the first of a series of shielded valves (the S.625) will enable experimenters to try out for themselves the circuits published in this book. I sincerely hope that they will not find my opinions as to the value of the new valve unduly exaggerated, but that in the main they will agree with me that this new method of high-frequency amplification is, as I have already said, unrivalled.

H. J. R.

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CHAPTER I

The General Problem

THE object of this book is to introduce to the wireless experimenter a new method in reception which I believe is destined to replace to a very great extent methods at present in use. In order that the principle may easily be understood it is proposed to review some of the problems of reception as briefly as possible in the first few chapters.

Wireless telephone transmitting apparatus, as is well known, sends out high-frequency ether waves which during periods of microphonic rest are of constant amplitude. These waves induce a voltage in any conductor, and the amount of this induced voltage depends upon the size of the conductor and its distance from the transmitter. The conductor if used for the purpose of reception is called an aerial. With the voltage induced, current and power can be obtained from the aerial and this power will enable various results to be obtained. High-frequency alternating currents do not readily lend themselves to the

operation of instruments; for instance, no ordinary ammeter can be made which is really sensitive to high-frequency current. High-frequency currents also will not affect a telephone, so that a secondary operation is necessary to enable detection to take place. This secondary operation is called rectification and is performed by a device which permits current to flow in one direction but not in the other. Many of these devices are known, the chief ones in use being crystals and thermionic valves.

The result of the rectification of high-frequency current is the production of direct current which will operate any such instrument as a milliammeter, providing this is a sufficiently sensitive device. A telephone, however, will not yield any sound with a direct current except when the latter is varied. When the microphone of the transmitter becomes active it varies the amplitude of the continuous high-frequency wave which is transmitted, and this, after reception and rectification, becomes a varying direct current which will affect a telephone more or less sympathetically with the air wave which is affecting the microphone. The essential apparatus in a receiver is thus an aerial, a rectifier, and a sound-producing instrument which is responsive to low-frequency changes of direct current.

The Aerial and Rectifier Efficiency.—The electrical waves radiated by the transmitter, in general, only affect conductors placed in a direction at right angles

to the earth. Thus a 100-ft. wire erected vertically will have the full force of the wave acting on it, but if this is placed so that 50 ft. is vertical and 50 ft. horizontal, then there will only be half the force applied to the aerial, and so on. Thus a wire 10 ft. high will only have one-tenth the force applied to it that a wire 100 ft. high would have. Now, all known rectifiers have a very awkward law of efficiency. The efficiency falls off with a decrease of the applied signals, so that if we obtain a sound of a certain strength with a 100-ft. vertical aerial, the sound will be much less than half as strong with a 50-ft. aerial. Also, an aerial placed at twice a certain distance from a transmitter will give rectified effects of much less than half those obtained at the original distance. Laws of this nature are very inconvenient in practice, and we shall see that they are the cause of many of the troubles of wireless reception.

A valve amplifier can quite easily be built to amplify low-frequency currents almost to any extent, and it would seem therefore that if our aerial is too small or too far away to obtain sufficient power for us comfortably to hear signals in the telephone, it would be a simple matter to amplify them with a low-frequency amplifier. But let us consider this matter in a simple arithmetical way. A signal of strength 10 gives, say, a sound in the telephones of 10; a signal of 5, however, only gives a sound in the telephone of 2·5 because of the falling off of efficiency in the

rectifier. A signal of strength 2·5 only gives a sound in the phones of ·6; all this because the rectifier is getting rapidly less efficient as the signals weaken. Therefore, if in the first case we require a magnification of 100 to work a loud speaker, by the time the signal has dropped to only a quarter of its original strength, we shall want a magnification of 1,600, and if the signal drops to one-sixteenth we shall want a magnification of 25,000. Obviously any attempt to receive signals one-hundredth part as strong as the original would be hopelessly beyond practical possibility.

Two alternatives remain to us. One is to increase the efficiency of the rectifier, and the other is to find out how to increase the input into the detector. The first alternative does not carry us very far, although I am not sure that everything possible has been done in this direction. In practice, although increase of rectifier efficiency would mean that greater L.F. amplification would be worth while, too much L.F. amplification introduces valve noise troubles. However, the second alternative is, up to a point, far easier to carry into practice than the first.

The problem, then, is to increase the force applied to the rectifier, and as the aerial size is usually fixed by practical limitations, we have only two ways in which we can do this. One is to cut out all losses wherever possible, and the second is to amplify, by means of valves, the high-frequency currents. Again,

cutting out the losses does not help to any great extent.

The first available method of amplifying is to use what is called reaction. A tuned aerial has a signal force, or voltage, applied to it and a current results, the value of which when the receiver is tuned depends on the resistance of the aerial system. The voltage applied to the rectifier is that existing across the tuning coil. If we allow a valve to amplify this voltage we should gain, and if a bit of the amplified effect is induced back into the grid of the valve, this in turn will be amplified. It is possible to carry out this procedure (called reaction or regeneration) up to a certain well-known point, when the system becomes unstable and oscillates. Reaction amplification is obviously definitely limited, but it is of very great value in receivers when the minimum of apparatus is desired and it is not required to receive from any great distances. The use of straight high-frequency amplification, however, is theoretically unlimited; practically, however, it has always been rather difficult to carry out to more than a limited extent, the chief reason for this being that the reaction, so useful in simple receivers to increase the amplification, cannot easily be controlled in receivers with great amplification, and the result is that these receivers are prone to oscillate, and this cannot easily be stopped.

How does a valve amplify? In the practical way valves are now used grid bias is usually applied to

the valve so that, speaking generally, the valve does not use up any power in its grid circuit because, although voltage is applied, no current flows through the valve grid circuit. The varying voltages applied to the grid alter the current in the plate circuit of the valve and we can either use these currents or pass them through resistances, capacities or inductances and thus produce voltages across these latter.

Under favourable conditions voltages can be obtained which are of considerably greater value than the original applied voltages.

The necessary condition for getting voltage amplification is that the impedance of the plate circuit outside the valve shall be of considerable value; thus, if it is equal to the valve impedance, the magnification of one-half the maximum possible value is obtained. An infinite impedance gives theoretically the full magnification, and unity magnification is obtained when the outside impedance falls to a certain small value. Obviously we must not let the outside impedance fall below this value, and a much higher value is really necessary to get a satisfactory amplification.

At low frequencies we have no difficulty whatever in maintaining very high magnification per valve, but at the higher frequencies accidental valve and lead capacities reduce the possibilities of magnification, and it is necessary to balance out these capacities with inductances to obtain the high external impeda-

ances we require to obtain magnification. Thus, on the broadcast range, the circuit of Fig. 1 will hardly give any magnification, due to the low impedance of of the stray capacities represented by C, but if we put from A to B a certain value of inductance (shown dotted), a very high magnification can be obtained at one particular frequency. The resulting circuit is a form of tuned circuit, and tuned circuits are nearly always employed now for high-frequency work.

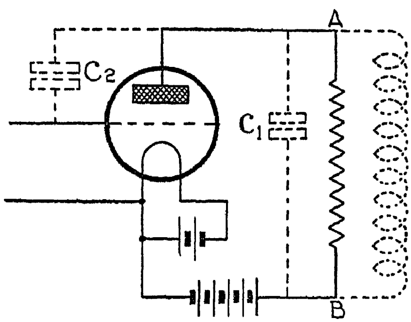

Fig. 1.—A Single Stage of Amplification

In addition to these shunt-capacity difficulties we have an even more troublesome one of grid-to-plate capacity (c_2 in Fig. 1) which is too small to have any serious effect on the low-frequency side, but is able to do a lot of damage in high-frequency stages by pouring the magnified energy back into the grid circuit and producing unwanted reaction effects.

The shunt stray-capacity effects are not very harmful because we do not mind using tuning circuits in the plate cilcuits of our valves. We shall see that actually

they are wanted for tuning purposes, but the capacity between grid and plate has caused great trouble in high-frequency work ever since the early days of the valve; also, as the characteristics of valves have steadily improved, the trouble has, if anything, increased.

It will be useful merely to note the various methods of countering the effect of this capacity. The chief one in use at the present time is the neutralizing method in some form or another. Neutralizing is

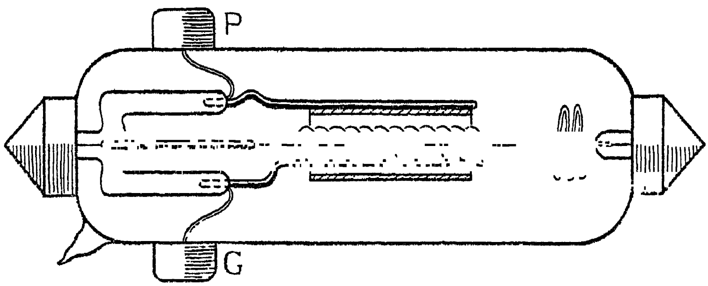

Fig. 2.—V.24 Type Valve, issued 1916

fairly easy up to a certain point, but it leaves one with circuits which have to be changed if the valve capacities vary and the so-called neutral circuits are not always entirely neutral over the whole frequency range.

Circuit-damping methods of oscillation prevention are also extensively used but are obviously wasteful, and certain other schemes depending upon phase changes are difficult to carry out and do not give the full value of magnification possible from the valves.

Very short waves of under 50 metres cannot easily be magnified at all by any of these methods except in

laboratory apparatus. The wisest step to take is to try and remove this capacity altogether and this idea has been in the minds of many engineers since about 1915.

Without going into historical matters too closely I may say that the first step to remove at least part of this capacity was taken with some special war valves, particularly one lot of the well-known R type made by the French, which had both grid and plate brought out at the side of the bulb. Another type made by

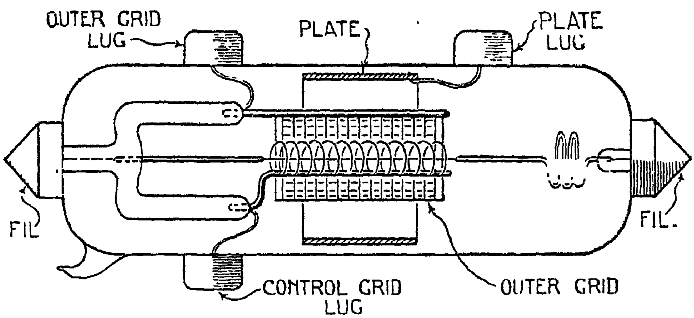

Fig. 3.—F.E.1 Type Valve, issued 1920

myself, the V 24 type (Fig. 2), was even better, in that practically all lead capacity was removed, the only existing capacities being between the actual plate and grid. This was still not enough, and the additional idea was evolved of *putting a shield between the grid and plate,* this shield being pierced with holes. A positive voltage was applied to the shield to draw the electrons through to the plate.

The writer produced valves of this shielded four-electrode type (the Marconi F.E. 1, Fig. 3) and used

them in cascade amplifiers several years ago. The shielding, however, was still not good enough, and the recent work of Hull in America and the Marconi Co. in England has resulted in valves which have the shielding carried to a very high degree.

The valves used by Hull and the Marconi Co. differ considerably. Fig. 4 shows a Hull valve as illustrated in his articles in the *Physical Review*. Fig. 5 shows in section one of the new Marconi D.E.S. 625 valves. This latter valve has been designed specially for use in connection with a shielding case. The

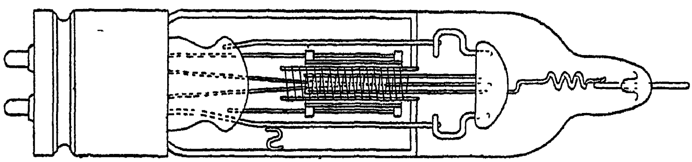

Fig. 4.—Hull Shielded Valve

main idea is that the shield grid shall be effectively a continuation of an outside shield.

The D.E.S. 625 valve which is illustrated in section in Fig. 5 consists of a glass tubular envelope, and across the centre at right angles to the axis of the tube are placed the various electrodes. Two of these electrodes are brought to the stem at one end and two to the stem at the other end. The first stem supports the filament and control grid. Both the filament connection and the control grid connection are attached to a cap of the ordinary French type with one pin removed. This will enable those who prefer

the ordinary French sockets to use them. The stem at the other end supports the shielding grid and the plate and these electrodes are connected to two pins of the second cap. These two caps have been arranged in the following way. The filament leads are attached to the ordinary filament lugs in the one cap and the control grid lead to the grid lug in the same cap, the plate lug being removed. On the other cap the outer grid comes to what would be a grid lug on the cap and the plate

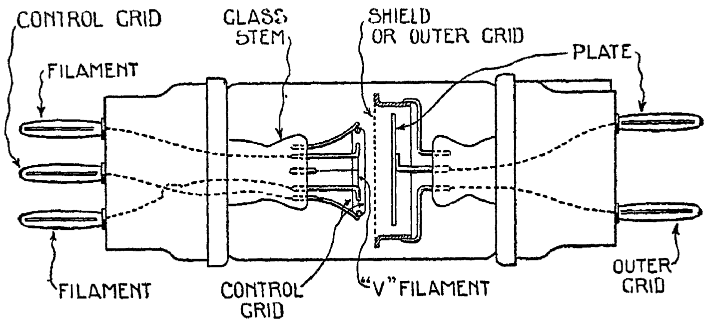

Fig. 5.—The New D.E.S. 625 Shielded Valve

comes to a normal plate lug. The outer grid and plate lugs are arranged to be in the same plane as the filament lugs, and this enables a simple system of clips as illustrated in Fig. 6 to be used, or, as an alternative, French-type sockets can be employed and the unused contacts of course disregarded.

The outer grid, the purpose of which is to shield the operating grid from the plate, consists of a flat grid structure with a ring in close proximity to the glass, and it is intended that the outside shield used

in the receiver should come as near as possible to this grid ring so as to continue the shielding of this outer grid. The inner or control grid is made more or less like a D.E. 5-type grid, and the advantage of this is that in manufacture the distancing of the filament from the control grid is easier and the constants of

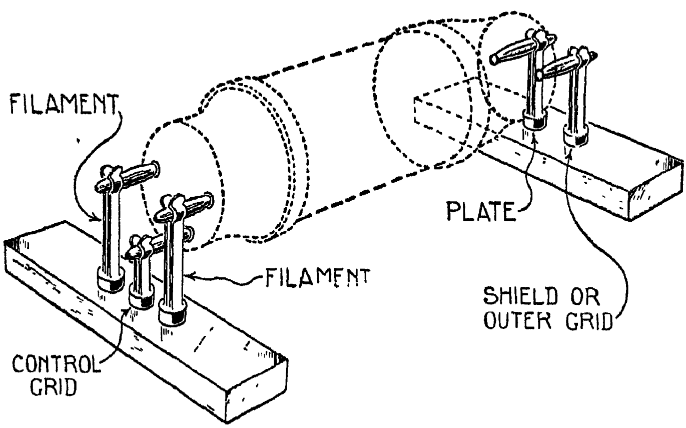

Fig. 6.—Simple Clip System for the D.E.S. 625

the valve can better be maintained. It is actually only necessary for this grid to be on the active side of the filament; the grid on the opposite side is not of any consequence from the operating point of view but only for convenience of manufacture.

The magnesium gettering by which the valve vacuum is maintained is arranged to be on only one side of the shielded grid, otherwise it would be liable to carry back high-frequency voltages to the input circuit.

The filaments of the first batch of these valves

produced are rated at 6-volt ·25 amp., a type which in the D.E. 5 valve has given every satisfaction for several years. It was thought that in the first issue of these valves it would be better to arrange for a filament of which there could be no doubt of the reliability. There is no reason, of course, that coated filaments should not be employed, and shortly tubes of this type will be produced. Owing to the way in which these valves are constructed, the capacity between the plate and the control grid is now very small and insufficient with average valves to set even the lowest damped circuit oscillating, but, of course, it must not be forgotten that there is still a small capacity remaining which may possibly show up under certain extreme conditions with picked valves. As I shall note later, a trace of added damping to any circuit giving trouble will stop oscillation.

The efficiency of this valve has been made as great as is practically safe, but it is quite easy to make a valve of twice the mutual conductance of the D.E.S. 625 by certain alterations in the dimensions. The magnification, however, would only be twice its present value and in most cases steps would have to be taken to damp circuits to prevent oscillation.

This neutral tetrode has, in my opinion, taken us one step nearer to the ideal receiver and it will at least enable the ordinary man to obtain or make a long-distance receiver at a lower price than was previously possible. Also, the ability to have under

control large values of high-frequency magnification will permit the constructor to simplify the rectification and low-frequency magnification stages of his set, and thus obtain, with greater ease, better quality. In addition, I think that eventually it will tend towards the production of receivers which will be more simple in operation than those in use at present.

CHAPTER II

Tuning and Amplification

In broadcast reception one big problem that we have to solve is to receive a certain station and cut out all other stations.

A modulated continuous wave consists of a band of waves about 12,000 cycles wide; at least, this

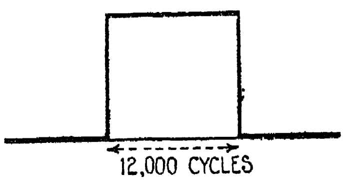

Fig. 7.—Ideal Tuning Curve

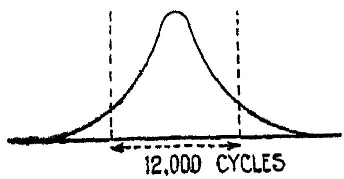

Fig. 8.—Practical Tuning Curve

12,000-cycle band is that which is of importance; obviously, then, if the tuning of the receiver can be arranged so that only 12,000 cycles are received, it will be an advantage.

In cheap commercial apparatus it is not possible to approach this ideal very closely, but we can examine briefly the conditions which tend towards perfection. The most difficult problem in tuning occurs when we are under the shadow of a local station and we wish to hear a station with a wavelength very near that of the local station. This generally means that the

local station is hundreds of times stronger than the one it is desired to receive.

To avoid any distortion the whole 12,000-cycle band of frequencies should be received equally, but it is usually necessary to permit a variation from this ideal. Thus in Figs. 7 and 8 the first is the ideal attempted, whilst the second is that with what we have to be content unless our apparatus is of an exceedingly expensive type.

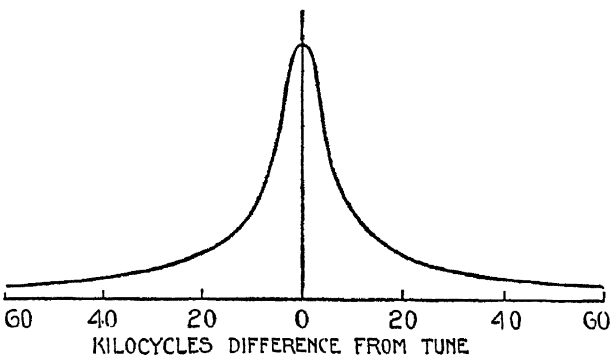

Fig. 9.—Tuning Curve of One Circuit

A single tuning circuit is quite incapable of producing a curve of reception even like this second curve; the best which it can do is something like what is shown in Fig. 9. In this, if the curve is made sufficiently rounded at the peak to cause no distortion, the reception is still a fair proportion of the peak value a long distance away from the tuning point.

The problem at the present time is solved by cascading tuning circuits, and we can approach the

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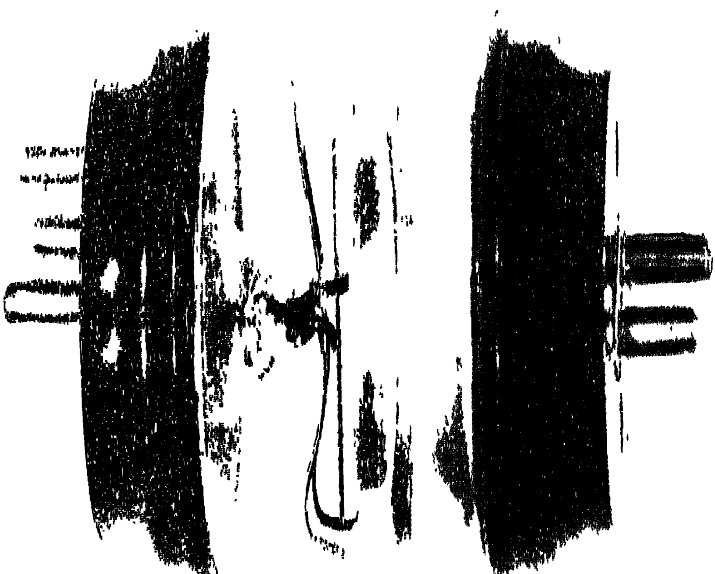


A specimen of the shielded valve (D.E.S. 625).

tuning of the second curve (Fig. 8) by means of a number of tuning circuits, each of which induces into the next as shown by Fig. 10. If the two sets of signals from the two stations were equal and moderately well separated in wavelength, then one tuning circuit would probably enable us to separate them, as it is only necessary for one station to be received from five to ten times stronger than the other for the latter to be negligible. If therefore in the broadcast band all stations gave equal signals, our operation

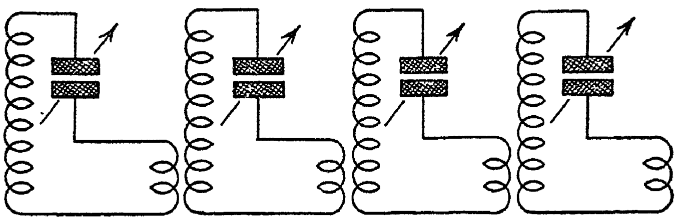


Fig. 10.—Cascade Tuning Circuits

would be to apply one tuning circuit and then amplify up until we had obtained sufficient strength. This is, of course, assuming that all these broadcasting stations are not jammed too closely together.

In practice, however, some stations are hundreds of times the strength of others, so that although we may minimise the strength of the powerful one by tuning to the weak one, the strong one may still be many times louder than the weak one. The weaker therefore the station is that we have to receive, the better must be the tuning in order to reduce the

strong one to a value which is small compared with that of the weak one.

As the weaker a station is, the more is the magnification required to receive it, it is obvious that in a good receiver the tuning and magnification are interconnected. It follows that the more the available magnification, the better should be the tuning.

It would be quite wrong to take a single tuning circuit and flatly amplify a large amount after this

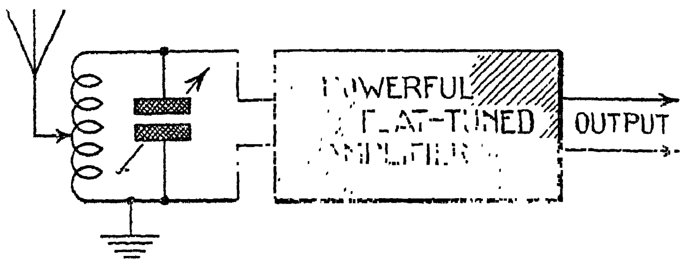


Fig. 11.—An Incorrect Method of Reception

circuit, as in Fig. 11, because we should get every station in at once, unless the local station swamped everything, as it probably would. We could certainly take the arrangement of Fig. 10 and apply the flat amplifier at the end and theoretically obtain the right result, but there are serious objections to this method, and one is that the receiver would have to be screened very expensively in order to prevent direct pick-up of the local station. If single valves had a really high factor of amplification (of several

thousands) probably this method of receiving (Fig. 11) would be used. It is easy to see that the number of tuning circuits required in cascade depends upon the amount of amplification, but the numerical values are of course only to be decided by experience. We can also see at once that a receiver which is only sensitive enough to get the local station needs only one circuit,

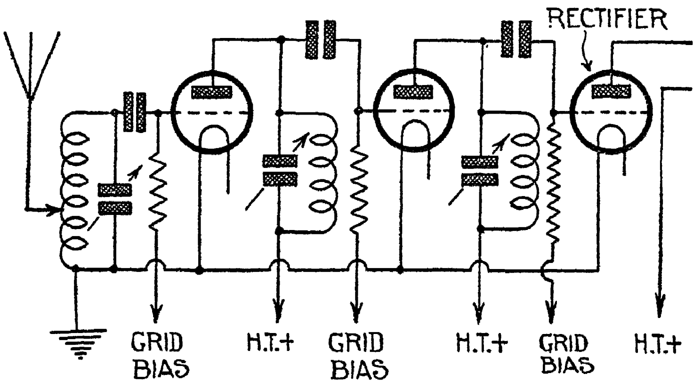


Fig. 12.—Valves in Cascade Amplification using Tuned Coupling Circuits

just enough to cut out the Air Ministry and a few high-powered telegraph stations.

As we increase the magnification so as to get other stations the tuning must be increased, otherwise the magnification is of no use. A second reason against the arrangement shown by Fig. 11 is that we usually require valves in cascade to obtain high amplification, and valves can only be cascaded on broadcast wavelengths by means of tuned coupling coils (Fig. 12).

It naturally follows that when we add another valve we automatically add another tuning coil. If in our receiver we have sufficient magnification to get all stations, the larger the number of tuning circuits we are employing the better will be our tuning, and also, obviously, the less the amplification per valve that will be required. For ordinary work,

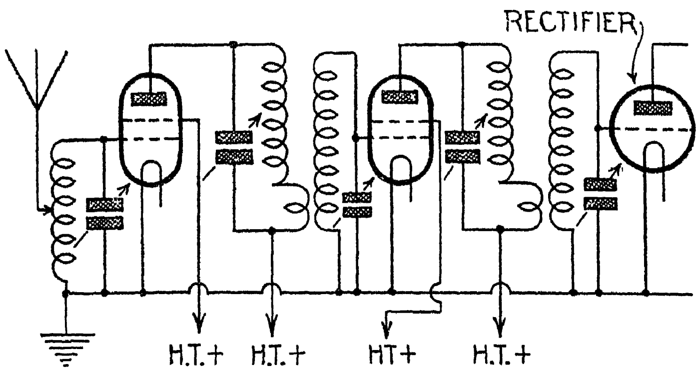


Fig. 13.—Increasing the Tuning without increasing the Valves in number

however, too great an increase in the number of circuits is an expensive solution of the problem and we have to compromise by using more magnification per valve and fewer circuits, otherwise the price of receivers would be prohibitive.

Reasonable results can be obtained, providing one is not right under the shadow of the local station, with three tuned circuits of fairly low loss type without the use of reaction. Undoubtedly, though, four or five circuits are better.

The Tetrode gives a magnification of about 30 per stage, and with this magnification two valves give a high-frequency magnification of about 900, using three tuned circuits. A reasonable tuning curve can be obtained with this arrangement, but nothing like so good as the curve of Fig. 8, because at least six circuits would be required to approach this result. To get the full value from a high-magnification valve like the Tetrode it would probably be necessary in more expensive receivers to adopt a scheme like Fig. 13, but obviously there must be many developments before low-priced receivers can be produced with so many condensers and coils.

CHAPTER III

Triode Characteristics

There are a number of factors in three-electrode valve operature, the interaction of which require to be carefully understood. I think that the easiest way to study them is to consider first of all the action between the filament and the grid when positive potential is applied to the grid, considering the plate as absent.

With different values of positive potential on the grid, different currents will flow, and from the data thus obtained a curve may be drawn (see Fig. 14). If this curve were a straight line, as it would be if the valve were replaced by an ordinary resistance, then we should be able to say that the voltage divided by the current was the resistance. As the curve, however, is not a straight line, the resistance varies from point to point and is obtained by taking the change of voltage over a small part of the curve and dividing by the simultaneous current change.

Of course, conductivity is the reciprocal of resistance, and I should not introduce the expression here but for the fact that one of the constants of the triode that is usually spoken about, the mutual conductance, or slope, is the conductance obtained from this curve

of Fig. 14. Two valves in parallel will have a curve twice as steep as one valve, so that in a way we can measure the qualities of a valve by the steepness of its curve.

It may be noted here that alteration of the grid mesh is not likely to alter this curve taken between the grid and filament.

If the plate is now introduced and a voltage applied

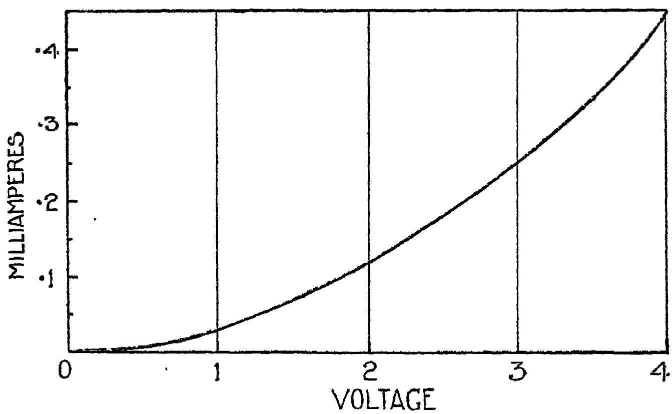


Fig. 14.—Characteristic of a simple Two-electrode Valve

to the plate, a current will flow to it. Let us assume that we maintain the grid voltage at some definite potential and change the plate voltage. The voltage on the plate has to act on the electrons near the filament to pull them to the plate; but between the plate and the filament is the shielding gridwork which partially nullifies the effect of this voltage.

The amount of this shielding is a definite quantity,

depending chiefly upon the size of the spaces in between the grid wires. Let us suppose that we find ten volts on the plate pulls one milliampere to it, and that one milliampere can be pulled to the grid by one volt on the grid, when the plate is absent. The ratio of ten volts to one is called the M value of the tube, and this M will be increased by decreasing the size of the spaces in the grid to give greater shielding effects.

It is fairly obvious that the original curve we obtained between voltage on the grid and current to the grid will merely have to have its voltage scale multiplied by ten to give us the curve of current flow to the plate with the grid at a fixed potential. This new curve will have a resistance ten times as great as the original curve and a conductance of one-tenth.

The original grid curve was independent of the size of the grid holes, and the conductivity at any point (which we named the mutual conductance) can now also be obtained in the full triode by taking the conductance of the plate curve and multiplying by the constant M. As the conductance of the plate curve is the reciprocal of the resistance, we get the mutual conductance as equal to $\frac{M}{R_A}$.

Manufacturers make series of valves, such as the D.E. 5A, D.E. 5, and the D.E. 5B. These valves have exactly the same physical dimensions except that the grid wires are differently spaced. The mutual

conductance of these valves therefore will be the same providing we use the same current value when taking the measurement, but the M value and R value will depend upon the spacing of the grid.

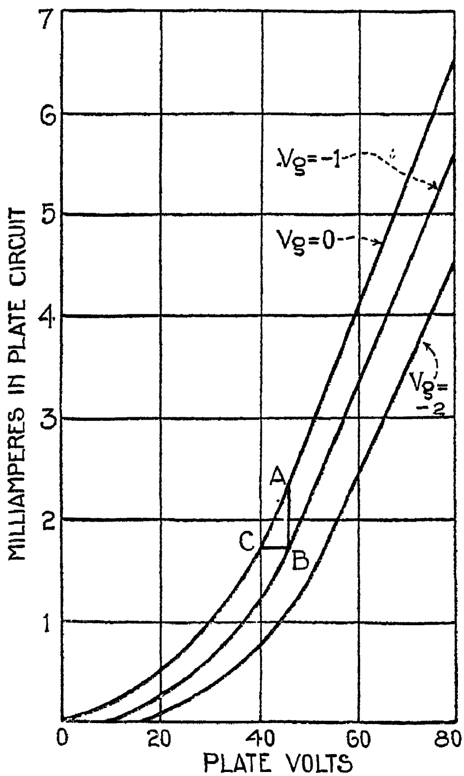


Fig. 15.—Characteristic of a Three-electrode Valve

From the curve of Fig. 14 it will be seen that the resistance of a valve usually decreases with increase of current. This is not always true, but in triode

work we tend to use the valves at a place where this is occurring, so that the mutual conductance or $\frac{M}{R_A}$ of a valve will usually increase as we:

(1) Increase the plate voltage.
(2) Make the grid voltage more positive.
(3) Increase the filament brilliancy, but to a minor degree.

The action of the plate current, when both grid and plate voltages are changing together, is quite simply seen from the effects of these independent actions. Thus if V_g is the voltage on the grid and V_A is the voltage on the plate, the total voltage acting on the electrons near the filament is $V_g + \frac{V_A}{M}$. We can now join into one equation our three chief factors in the valve, the plate current flowing I_A, the grid volt V_g, and the plate volts V_A. We represent this equation as a graph, such as Fig. 15, by drawing a series of curves at different fixed values of one of the three factors, the other two being variable.

Thus Fig. 15 shows a series of curves at fixed values of grid voltage and various values of plate current and plate voltage. In this figure at one place I have drawn a triangle ABC. At this position on the graph a change of plate volts CB gives a current change BA, and the resistance of the valve at this point is $\frac{CB}{AB}$. The line CB measured on the horizontal volts scale

is the M value of the valve because if we change the plate volts from C to B we can bring the valve back to the same current value by altering the grid volts by one volt. The line AB on the vertical current scale is the mutual conductance of the valve because

$$R_A = \frac{CB}{AB} \text{ and } M = CB \text{ so that } \frac{M}{R_A} = \frac{CB}{\frac{CB}{AB}} = AB$$

So far I have only considered the action of the valve without any regard to the circuits that are outside it, but of course the valve would not be much use without circuits attached to it. The grid circuit will cause us no trouble theoretically, because in nine cases out of ten the grid is arranged with a negative potential on it, so that any volts applied will not be reduced by any grid-current drop. But the plate circuit is different, for suppose we insert in the plate circuit a resistance R, a current will still flow, but the voltage on the plate will be the total voltage minus the drop of volts in the resistance, and this rather complicates the action.

Without any external resistance a rise of grid voltage gives an increase of plate current, the plate voltage remaining steady; but with any resistance in the plate circuit, the plate voltage will fall as the grid voltage rises and the fall will be accompanied by an equal rise of voltage across the resistance. It will be noted, that really there is no addition of actual voltage to the plate circuit; this remains constant

and equal to the H.T. battery voltage, but for all practical purposes we can assume that one volt change on the grid is accompanied by M volts change in the plate circuit, which M volts are split up in the ratio of the valve and the circuit resistances. So that if R_A is the valve resistance at the operating point on the characteristic, one volt grid change will result in $\frac{MR}{R + R_A}$ volts across the resistance (formula 1).

This step is admittedly obscure without further proof, but to avoid making the explanation complex here, in Appendix A I have inserted the algebraical proof of the point.

The expression $\frac{MR}{R + R_A}$ can be simplified for further use by dividing both top and bottom by $R\,R_A$, an operation which does not alter its value, and we get successively

$$\frac{\frac{MR}{R\,R_A}}{\frac{R}{R\,R_A} + \frac{R_A}{R\,R_A}} = \frac{\frac{M}{R_A}}{\frac{1}{R_A} + \frac{1}{R}} = \frac{K}{\frac{1}{R_A} + \frac{1}{R}} \quad \text{(formula 2.)}$$

where K is the mutual conductivity of the valve.

Fig. 16 represents a valve with a resistance in its plate circuit and, unfortunately, if we alter R, we entirely alter the setting on the valve characteristic so that we have to re-determine the value of R_A. To avoid this in the following discussion I have converted the circuit of Fig. 16 to Fig. 17, in which

the choke and the condenser B are so large that for all ordinary frequencies they do not alter the circuit.

Now, alterations in R do not shift the position on the valve characteristic and we can determine several facts. For instance, if R_A is equal to R and we make one volt change on the grid, M volts are split up equally between the valve and resistance and the amplification is $\frac{M}{2}$.

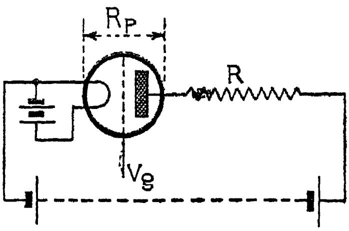


Fig. 16.—Valve with Resistance in Plate Circuit

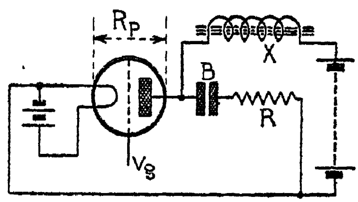


Fig. 17.—Equivalent Circuit to Fig. 16

If R is infinite, formula 2 gives us the amplification as $\frac{K}{\frac{1}{R}}$ and because K is $\frac{M}{R_A}$, this becomes $\frac{M \times R_A}{R_A} = M$, so that in the case of an infinite resistance the magnification is M.

M is so intimately connected with the quantity of magnification we get that it is called the Magnification Constant.

The formula 2 enables us to determine a still more important point, and that is what happens when the M value of the valves is altered.

We have seen that such valves as the D.E. 5 series have at the same current value the same value of $\frac{M}{R_A}$ or K, the mutual conductivity.

Suppose the mutual conductivity of this series is one milliampere per volt or 1/1,000, then when R_A is 10,000 ohms, suppose R is 50,000 ohms, formula 2 gives us a magnification of

$$\frac{\frac{1}{1,000}}{\frac{1}{10,000}+\frac{1}{50,000}} = 8{\cdot}3$$

Now take R_A as 50,000 ohms, leaving the same value as R, and the magnification becomes

$$\frac{\frac{1}{1,000}}{\frac{1}{50,000}+\frac{1}{50,000}} = 25$$

Again, take R_A as 200,000 ohms and the magnification is

$$\frac{\frac{1}{1,000}}{\frac{1}{200,000}+\frac{1}{50,000}} = 40$$

All the time, therefore, the magnification is going up as R_A is increased, and we shall find that it reaches a limit of K R when R_A is infinite, or in this case,

$$KR = \frac{1}{1,000} \times \frac{1}{50,000} = 50.$$

Still further magnification can be obtained by

increasing R theoretically up to an infinite magnification wherm R is infinite.

The chief points that have come out are these:

(1) With the same valve the maximum magnification is M with infinite R.

(2) With a valve of mutual conductance K in which M and R_A are carried to an infinite value

M.	Mutual Conductance.		
10	·6	milliamps	per volt.
20	·35	"	"
40	·15	"	"
80	·08	"	"

Fig. 18.—Table giving Mutual Conductance at various values of M

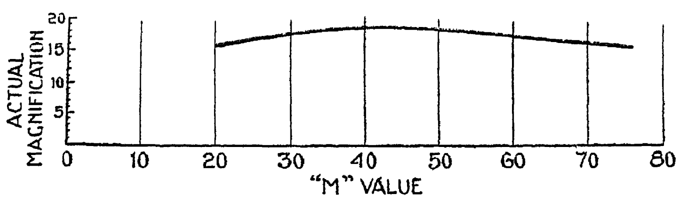


Fig. 19.—Magnification at Constant Voltage on a Valve with varying M value

the maximum magnification is K R, which can be as high as we like to make R.

There is, of course, a serious practical snag in all this reasoning with the triode, for to obtain this condition of constant mutual conductivity, as we alter the M value we have continually to raise the high-tension volts as M is increased, until very soon the voltage is impracticable.

Actually, if we take a practical case where the high-tension voltage is fixed, then the mutual conductivity rapidly falls with increase of M with any one series of valves. For instance, in the D.E.P. 215 series, Fig. 18 gives the mutual conductance at various values of M and Fig. 19 the resulting magnification to a resistance R of 240,000 ohms.

Thus we arrive at an optimum value of magnification at a certain value of M unlike the condition previously discussed where the optimum is when M is infinite.

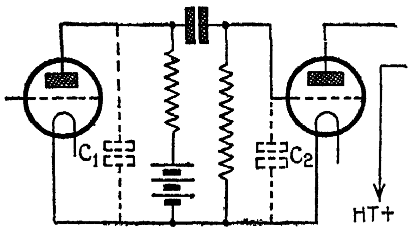
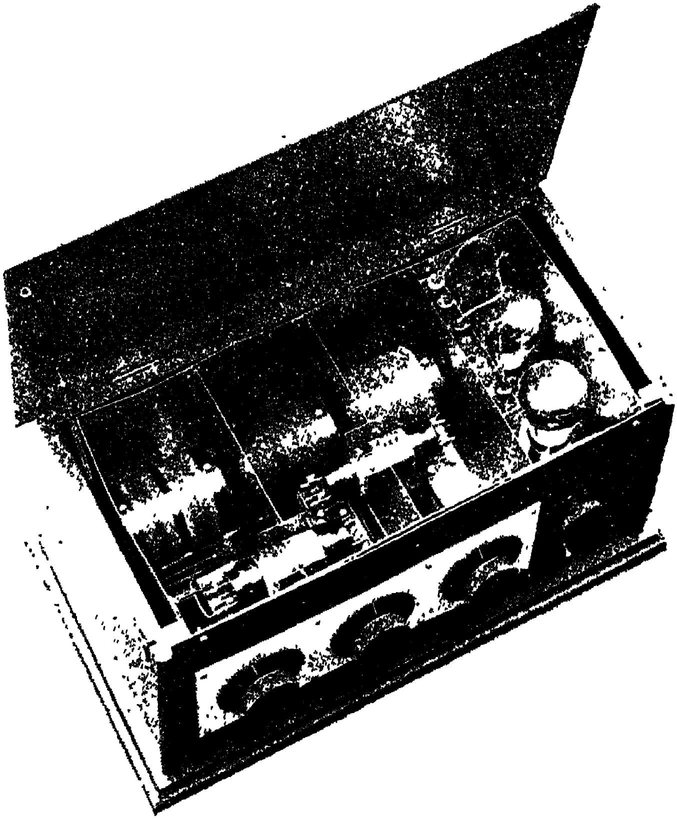


Fig. 20.—Resistance Amplifier showing Valve Capacities C1 and C2

If the resistance R, Fig. 17, is replaced by an impedance, either inductance or capacitative, the magnification can be obtained by similar calculations, and as we are chiefly concerned with high-frequency magnification this point is very important, because actually we cannot get away from capacity effects.

Thus any attempt to amplify with a resistance amplifier even a thousand kilocycles is hampered by the actual valve capacities, which may be as high as ·00004 mfd.

Take a circuit such as as shown in Fig. 20. The resistance R is actually shunted by two valve capacities



A four-valve broadcast receiver: 2 H.F., plate-bend rectifier R/C coupled to power valve. Plug-in coils for range change; connections as in Fig. 1 (page 7).

Facing page 32

c1 and c2, and also by the accidental capacities of the resistance and coupling condenser. These latter may amount to as much as the valve capacity and we are quite likely to get a total capacity of ·0001 mfd. At a thousand kilocycles this capacity has an impedance of about 1,600 ohms, so that a very high mutual conductance will be required to give a serious magnification with such a low impedance.

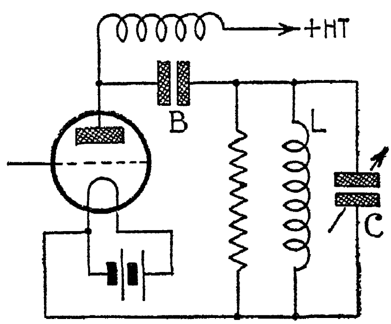


Fig. 21.—A Tuned Plate Circuit

The cure for this trouble, however, is quite simple, because an inductance can be arranged to balance out this capacity at any one frequency; this process is now general in H.F. amplifiers, and in fact renders them practicable.

The following ways of roughly considering quantitatively how high-frequency circuits magnify is useful.

If to the resistance circuit of Fig. 17 we add L and C as shown in Fig. 21 and assume that L and C have no losses and are set in tune with the frequency being used, then the whole circuit is not changed by

to infinity, if there is no disadvantage otherwise, gives us the full tuning of our coils and condensers.

It would be useful to consider what happens when we change the ratio of L and C. Suppose L is doubled and r is doubled also, which would happen if we put two inductances like L in series, C would have to be halved to bring the circuit into tune again, and the equivalent shunt R would not be doubled. In the limiting case when M and R_A are both infinite we could get twice the magnification but the tuning would be the same as when using L and C.

But if we wound our two L's into the same dimensions as L, it is likely that the resistance would be 4r. This would mean that the equivalent shunt would now be the same as with L and C; the magnification would be the same as with L and C but the tuning would be twice as flat. We have thus a control of magnification and tuning by altering our circuit, the only limitation being practical dimensions such as the sizes of coils and the capacities of condensers available.

What will happen if we tapped the plate of the valve down the inductance, or what is the equivalent, use a ratio step-up transformer? Roughly, R across a whole coil is equivalent to $\frac{R}{4}$ across half the coil, that is, it will give the same damping, so that tapping down merely decreases the value of R in the valve circuit, and in the optimum magnification case where M is infinite, this is a positive disadvantage.

In the practical triode case, where the high-tension is fixed, tapping down is not a disadvantage, and Fig. 22 shows that at each tap position there is an optimum value of M.

In the ideal constant mutual-conductance case however, at whatever tap we are fixed, the highest magnification is given by the highest M value.

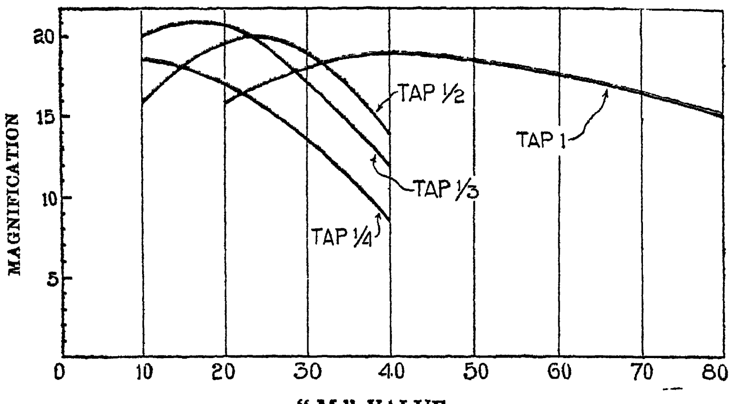


Fig. 22.—Magnification given at Various Taps with Valves at Constant Voltage

So that if R is the equivalent shunt across the whole coil and $\frac{R}{4}$ across half the coil, then in the first case the magnification is KR and in the second case $\frac{KR}{4}$, but, of course, as in the second case we have a step-up ratio transformation of 2 and 1, this latter magnification becomes $\frac{KR}{2}$, that is, half the best value.

All this points out the great necessity of valves of

high mutual conductivity and of high M values. It also indicates how severely we are limited with triodes by the fact that the practical value of mutual conductance goes down as M rises.

Possibly more serious consideration has not been given to these points in the past because of the fact that another defect of the triode has prevented large magnification being obtained, and that defect is due to the capacity between grid and plate. This capacity enables magnified energy to leak back and upset the input or grid circuit and, as is well known, this produces a self-oscillating system; even the most carefully constructed bridge or neutralizing system fails in practice if the highest magnifications are attempted.

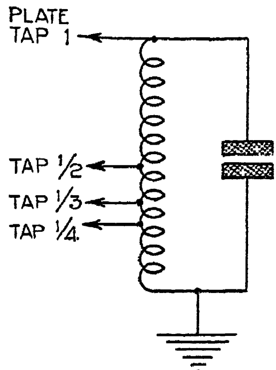


Fig. 22a.—The Tap Positions referred to in Fig. 22

The tetrode, as I shall show, solves in a bold way the difficulty of obtaining a high $\frac{M}{R_A}$ with high values of M at a reasonable voltage. Most important of all, it enables an effective shield to be inserted between the grid and plate to prevent the energy flowing back from the plate to the grid and thus causing instability.

With these tetrodes the magnification and tuning possible are only limited by practical considerations.

CHAPTER IV

Tetrode Characteristics

In the last chapter only triode characteristics were considered. In this chapter I shall endeavour to explain the action taking place in a 4-electrode valve or tetrode used in a particular way suitable for high-frequency magnification.

In this particular arrangement the grid, in proximity to the filament, still remains as the control electrode, but the plate is converted into a fine-mesh second grid, and outside this second grid is placed a plate.

Suppose in such an arrangement we put a positive potential on the outer grid and a small negative potential on the inner grid, then the whole arrangement is like a triode, and we can set it at some position in a triode characteristic. If we now apply a potential to the plate, it can easily be imagined that electrons dragged up to the outer grid and shot through may be attracted by the plate, thus robbing the outer grid of its full current. But if this outer grid is fine enough, any H.T. voltage on the plate will not leak through the outer grid as its M value will be so high. Therefore the plate will only be able to rob current

from the outer grid and not produce any extra current for itself.

In consequence the sum of the two currents to the plate and outer grid will be approximately the same as the current to the outer grid if the plate was out of action.

Now consider what happens as we steadily increase the plate potential, leaving the inner and outer grid potential fixed. A rapid rise of current with voltage

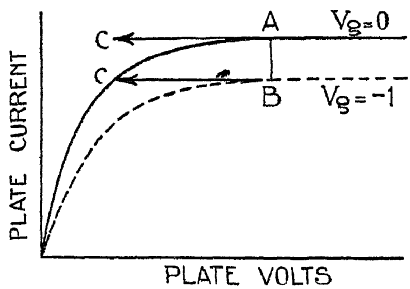


Fig. 23.—Characteristic of an Ideal Tetrode

will occur and when the plate has robbed the grid of a large proportion of its current, the curve will become level.

The result we should expect would be a curve like Fig. 23, where the bend to horizontal takes place quite early. If we now alter the inner grid volts, say by 1 volt more negative, we shall get a new characteristic like the dotted line and so on.

When considering triodes we drew a triangle ABC on the plate-current plate-volts characteristic, but if we

attempt to draw the triangle in the case of Fig. 23 we find that AB can be drawn easily, but BC and AC meet a long way away.

Reasoning from the triode case, AB is the mutual conductance of the tetrode and this should be nearly as high as the mutual conductance of the same valve as a triode with the outer grid replaced by a plate because any loss will be due to absorption of current by the second grid and this is small by measurement.

But BC was the M value, so that this has become almost infinite and $\frac{BC}{AB}$, the RA of the valve, is almost infinite.

If we had drawn the triangle before the curve had become horizontal, the M and RA would have been less, so that here we have an arrangement in which with a finite good mutual conductance the M and RA can be raised from low to extremely high values without excessive voltages on the plate. We have seen in the last chapter that this will tend towards high magnification and good tuning. The mutual conductance is mainly affected by the mechanical dimensions of the arrangement as a triode. Larger areas of filament, therefore, or closer spacing of inner grid from the filament, smaller negative voltage on the inner grid or larger voltage on the outer grid will all tend to a better mutual conductance.

Unfortunately, for the simple theory given above, Hull several years ago discovered that a secondary

action takes place when the electrons are shot through the outer grid. They apparently hit the plate and by collision produce new electrons. These latter are then dragged back to the outer grid if the plate voltage is not high enough, so that instead of a simple

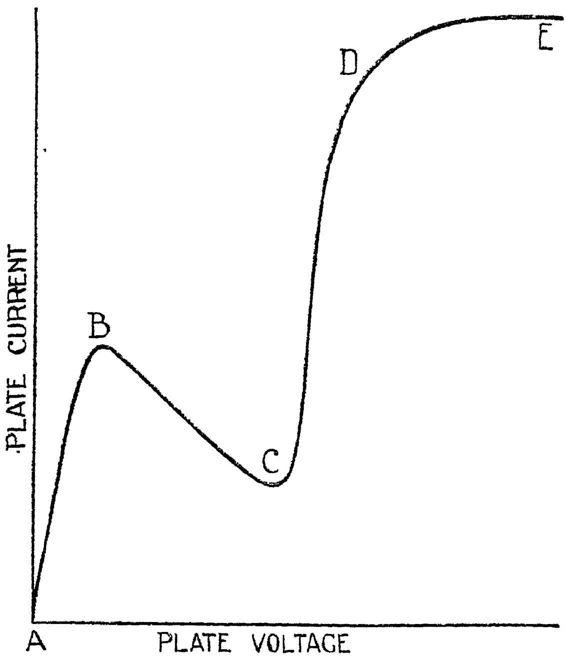


Fig. 24.—Real Characteristic of a Tetrode; Outer Grid at 80 Volts

characteristic like that shown in Fig. 23 we get the very peculiar one of Fig. 24. From A to B the action is as we initially expected, but from B to C the current actually decreases as the voltage rises—a condition known as negative resistance. The valve when used

in this condition was called by Hull a Pliodynatron. From C to D there is some attempt at recovery from the complex characteristic, because here, the secondary electrons produced at the plate cannot get back to the outer grid owing to the plate voltage now being sufficiently high.

The shape of the whole curve can be altered in various ways. Thus, if the outer grid volts are reduced we can avoid the negative resistance drop and

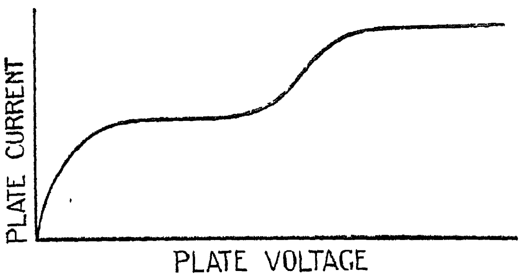


Fig. 25.—Tetrode Characteristic with Lower Outer Grid Voltage

get a curve like Fig 25, although in practice with ordinary construction the valve will not now be so good. Hull also produces this curve by covering his plate with a special material.

The whole of the characteristic from B onwards would now be available, most of it with a high value of M. It is possible to use the characteristic from B to C for high-frequency work with very high magnification effects, but as a general thing the effects are rather like reaction effects and are somewhat critical. Also, as our modern circuits are usually

of low enough resistance for undistorted reception, at the moment I do not think this part of the curve is very useful; the point B, however, is very useful, and from D to E it is very valuable indeed. Also, the

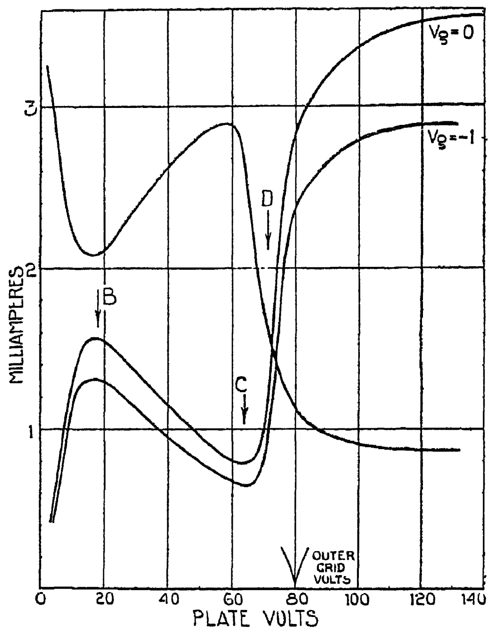


Fig. 26.—Characteristic of Marconi D.E.S. 625

curve from B to C when lower volts on the outer grid are employed may become of great use.

Fig. 26 shows the actual characteristic of a Marconi D.E.S. 625 with 80 volts on the outer grid and Vg = 0 and − 1, and on the same diagram is given the outer grid current with Vg = 0.

Fig. 27 indicates in a table the values of R_A, M,

and $\frac{M}{R_A}$ at various values of plate volts, and it will be seen that although the maximum values are not infinite, they would get very much higher at higher plate volts. The mutual conductance is actually improving as the M value increases, which is an inversion of what happens in practice when triodes are used.

Plate Volts	Vg	Vog	R_A	M	$\frac{M}{R_A}$ Ma. per volt
80	0	80	11,000	4.4	·4
90	0	80	40,000	16	·4
100	0	80	65,000	33	·5
110	0	80	116,000	56	·5
120	0	80	175,000	112	·64

Fig. 27.—Table Showing Valves at Various Plate Voltages

For the first time we have a valve where the M and R_A values are continuously variable from low to high values, a factor which in certain circumstances may be a useful property.

Reduction of filament current reduces the mutual conductance, as does also increase of negative grid bias and decrease of outer grid potential. Any of these three variables may be used to control magnification and the effect is very useful in multi-valve receivers with several tetrodes in cascade. The changes of strength can be made quite large. The simplest control is by filament brilliancy, but as it

is unwise to run thoriated filaments at too low a temperature, grid bias can be used to give large changes and filament brilliancy small changes.

When using these D.E.S. 625 tetrodes in this special way the following points may be noted. The best magnification is usually given with the outer grid at 80 volts and the plate at 120 or more. It is not advisable to exceed 80 volts on the outer grid on account of the vacuum of the valve. This setting is always advisable in sets which have variable reaction.

The best tuning is given by using the valve at the point B on the curve where the resistance is infinite or slightly negative, and the magnification will be found quite good at this position. This setting is not so useful in cases where reaction is being used.

For various purposes lower outer grid volts may be used. For instance if for better tuning it is desired to add another tuning circuit to a receiver without considerably increasing the overall magnification, one useful way is to lower the outer grid volts to about 30 and put the plate volts to about 16. The magnification will now be only ten to twenty per valve, but with three valves this will make possible a receiver of exceptional range and tuning. No valve damping is introduced into the circuits because at this position the valves are of infinite resistance.

Gradually more of the possibilities of the characteristics of these valves will be discovered, but in

this book I desire to concentrate chiefly on the high-frequency amplification side of the work as this is the section of wireless which has been least developed. Tetrodes may be useful later as rectifiers and low-frequency amplifiers and they will doubtless provide a new field for interesting research.

The tetrode not only solves the problem of obtaining optimum magnification in high-frequency circuits, but its second great property of effectively stopping the magnified energy from flowing back to the inner grid from the plate enables us to get this magnification without fear of oscillation trouble and without the use of neutralizing circuits.

If two tuned circuits are connected together through a valve, energy can get back in several ways from the plate circuit to the grid circuit; for instance, the tuning coils can induce one into the other. There may be sufficient inductance or resistance in the common leads to the batteries to give back coupling, but all these difficulties can be avoided by care in design and constructional work. The cures are more or less obvious and easy to apply.

Shielding is now the commonest way of preventing induction backwards through a receiver, but until recently there was one place where shielding was impossible and that was between the grid and plate of the valves and between the lead wires from these electrodes.

By carefully constructing a tetrode with a fine-

mesh outer grid, a very large proportion of this induction can be prevented by the action of this second grid; in addition, if care is taken to avoid capacity between the lead-in wires and effectively shield the grid and plate leads from one another, all induction can be effectively prevented.

In the Marconi D.E.S. 625 valve, the valve and the system on which they are to be used have been to some extent considered together. The coils, con-

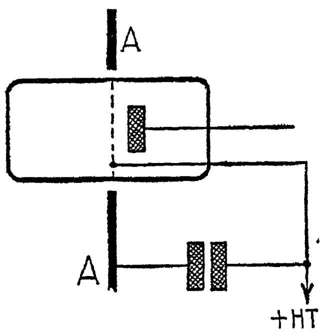


Fig. 28.—Method of making Outside and Inside Shield Continuous

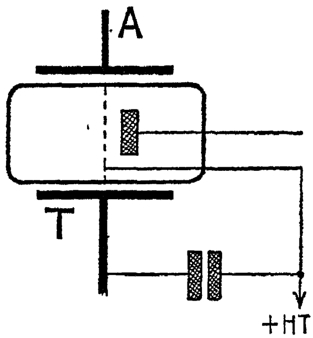


Fig. 28A.—An Improvement on Fig. 28

densers and leads of the grid and plate systems have to be electrically separate, and it was considered that this separation should also be arranged to assist in the separation of the valve electrode and the leads.

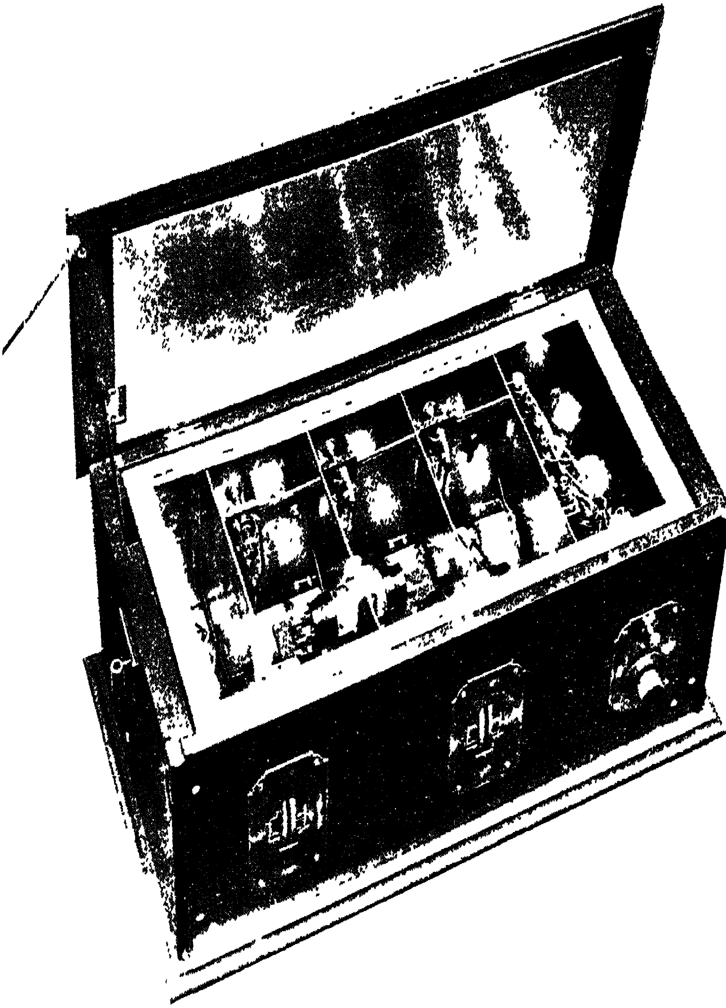
The general idea carried out in the construction of the D.E.S. 625 has been to extend the second or shield grid to the sides of the glass envelope so that this grid shield can be electrically extended outside the envelope by the metal shielding in the receiver.

Thus on the diagram Fig. 28 the valve is shown inserted in a hole in the shielding plate between the two circuits and the outside shielding plate AA is earthed, as is also the second grid through the condenser shewn.

In Fig. 28A is shown an elaboration of this scheme in which the valve is inserted in a tube which is fixed in the shielding plate. As a usual thing it will suffice if the valve is in a slot in the shielding plate, as this is a convenient arrangement if it is required to remove the valve quickly.

Rather better shielding can be given, if necessary, when using this slot arrangement by slipping a thin copper or tinfoil tube over the valve before putting in its clips; as the copper tube will be earthed by contact with the shielding plate, the arrangement will be practically as good as that shown in Fig. 28A.

It will be noted now that the only way that electrostatic lines can get from plate to grid is through the holes of the outer grid, and these have been made of sufficiently high M value effectively to remove any induction.



A six-valve broadcast receiver for frame reception. 3 H.F., plate-bend rectifier, and two L.F. stages. Long-wave or short-wave broadcast by switching. Connections as in Fig. 42 (page 66).

CHAPTER V

H.F. Amplification with the Tetrode.

In general the simplest circuit to use with the tetrode for H.F. amplification is that shown by Fig. 29.

As pointed out in an earlier chapter there is no necessity to use ratios of transformation in the plate circuits, so that the circuit of Fig. 29 is as good as any. For maximum sensitiveness it is preferable to keep the inductance high and the capacity low and it is better to use stranded wire, a convenient kind being 27/44 silk-covered and enamelled wire.

As the capacity in the usual tuning apparatus varies of course from small values up to a maximum, it is impossible in this simple way to keep the magnification and tuning constant, but the change will not be noticed to the extent that it is in an ordinary neutralised circuit.

A condenser with a maximum value of ·0003 mfd. is suitable and the inductances can be wound accordingly. I think some form of astatic winding is preferable for the inductances—the particular form is not of much importance—I prefer to use a winding on one cylinder with half the winding a right-handed spiral and the other half left-handed; the spectacle

type of astatic coil is quite good also. The coupling condensers need not be larger than ·001 mfd. but they should have good insulating qualities.

If undamped Litz coils are used as shown in Fig 29, even with the greatest precautions, a picked valve will sometimes have a slight tendency to oscillate because there is still a trace of back feeding after all precautions are taken; my practice is to damp the

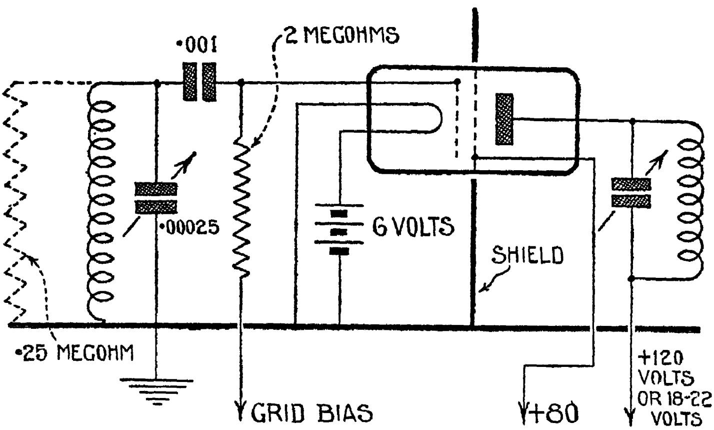


Fig. 29.—Simplest Tetrode Circuit

grid circuit with a shunt (see Fig 29) to prevent any trouble. The shunt should never need to have a lower value than 250,000 ohms, and this, if necessary, can conveniently be the leak through which the grid bias is fed. In general the shunt will only be necessary on the first input circuit of a receiver as the remaining coils are damped by the tetrodes attached to them.

The damping applies particularly to a frame aerial

which is sometimes of very low resistance and the slightest stray reaction will set the system oscillating. Perhaps in the case of this first coil or frame, solid wire would be just as good as Litz, for the reason that it is itself sufficiently damped without the shunt. In building up amplifiers, both magnetic and electrical shielding are very essential as the magnification per

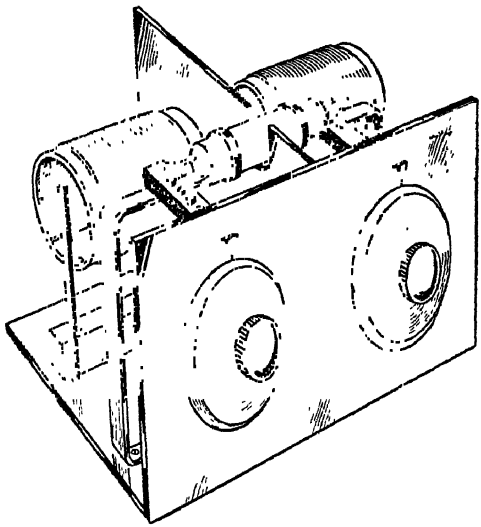


Fig. 30.—The Shielding Arrangement for One Stage H.F. Front, bottom and centre-piece are of metal

stage is between 30 and 50. The shielding should very carefully be carried out and all reaction due to avoidable coupling removed before any damping is applied. With one stage I find that a copper construction such as is shown in Fig. 30, in conjunction with blocking condensers and astatic coils, is sufficient.

Fig. 31 is a view of a single H.F. stage with added detector and L.F. I am not much in favour of shielded coils, as these still leave the necessity for electrostatic shielding in the leads and condensers. I think it is better to shield the whole circuit as shown. With two valves in cascade much better shielding is required as the magnification is really big, and when a frame is used which is to be brought near the receiver, a metal lid is almost essential.

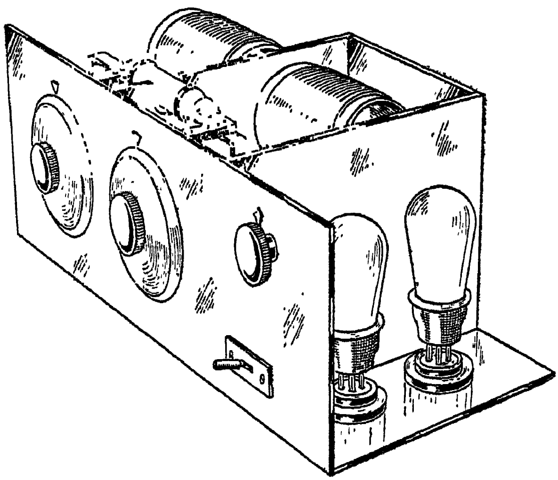


Fig. 31.—Shielding in a 1-Stage H.F. Detector and L.F.

The rectifier itself is a considerable source of reaction trouble, and all high frequency must be blocked from going further than the rectifier through the low-frequency amplifier; in addition the rectifier must be properly surrounded by a conductor to prevent a field spreading back to the aerial or other circuits.

These points become of the utmost importance when using two and three high-frequency stages of high frequency, although they are not so important with only one stage. The shielding used in a complete four-valve amplifier is shown in the photograph of a four-valve set. This is an excellent example of the value of the new valve in that a long-distance receiver is produced, with an inefficient plate-bend

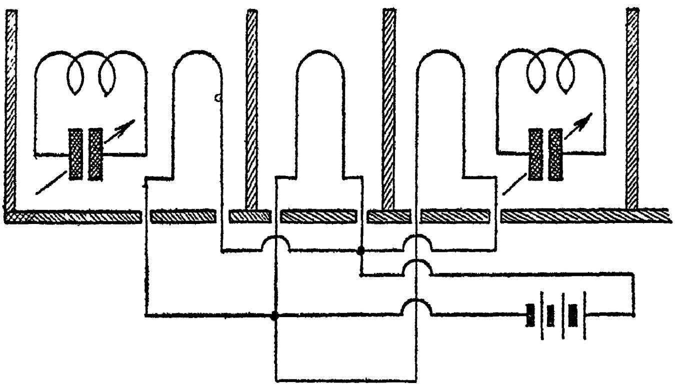


Fig. 32.—How Filament Circuits can give Reaction

rectifier driving the power valve without any intermediate low-frequency magnification. To do this it is obvious that the high-frequency magnification must be very great; in practice it averages about 1,000 per two valves.

In a three-stage high-frequency amplifier still further precautions are taken in the shielding. All joints in the shielding case should be soldered up and a metal top used, especially if a frame is to be brought

near to the receiver. The photograph shows the shielding arrangements of a six-valve amplifier in which two stages of resistance-coupled low-frequency are used after the rectifier.

This receiver provides practically the limit of reception possible on a small 1-ft. frame but considerable care is required in the design to obtain real stability. In this set the magnification available is about 30,000 on the high-frequency side and, if less than $\frac{1}{30,000}$ of the output signal gets back to the frame, oscillation will start. The circuits of both these receivers will be given later.

Apart from shielding, it is necessary to prevent inter-coupling along common battery leads. With one stage of high-frequency, a 1-mfd. condenser will be ample across the H.T. battery, but considerably greater care must be taken with two stages. First of all the common filaments are a source of induction, and one way in which they can cause trouble is as follows:

If the wiring is carried out so that in each department there exists an open loop, these loops are in parallel and are connected to the battery by an inductive lead (see Fig. 32). Any high-frequency field near the last loop can easily induce a current in the first loop and this can consequently induce back into the input coil. I usually earth the negative leg of the filaments to the metal case and run the positive

lead close to the metal case so that no large loops are formed.

Another good method would be to wire to each filament with a lead-covered pair of wires. Filament leads are usually taken to a switch and filament resistance, and as this is very often near the rectifier valve, there is a tendency for high-frequency to be sent back to the input circuit.

No serious troubles need be expected with only one tetrode in use, and the following notes really apply to two or more in cascade.

The judicious use of condensers will cure most troubles, providing the wiring is done so as to prevent circulating currents. The main blocking necessary is at the bottom of the outer grid (O.G.) and plate circuits and I have adopted a system of systematically using condensers for each lead, particularly when there are three high-frequency stages. This may be wasteful and not necessary in all cases, but it is the safest thing to do. Fig. 33 shows the blocking condenser arrangements in one high-frequency stage. The least important blocking is that at the bottom of the grid leaks. The blocking system is described in the next chapter, in which the various circuits are dealt with.

The use of the correct type of condenser blocking is a very important matter and some Mansbridge condensers are not very good for this purpose. Condensers of ·1 to ·2 mfd. are quite large enough for the purpose if properly made. Those who have pulled to

pieces a Mansbridge condenser will have noticed that it is made by rolling up long sheets of foiled paper. This foiled paper has a high resistance, and the result is that usually the only part of the condenser that is in action for high-frequency work is the first foot or so. By inserting a large number of connections at

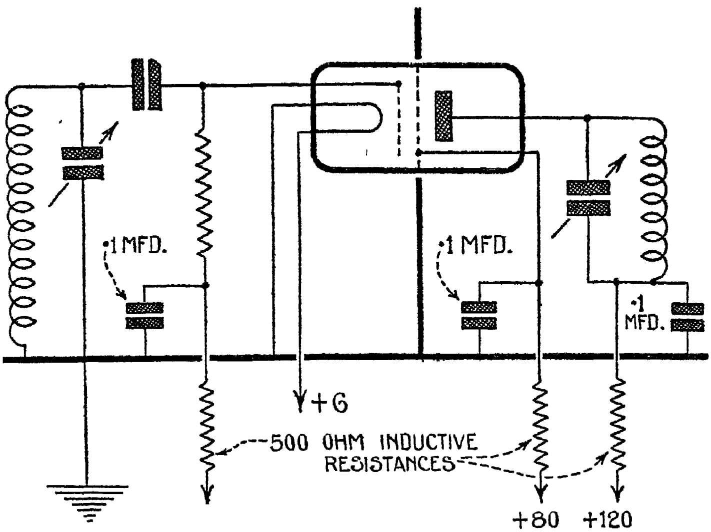


Fig. 33.—Condenser and Resistance Blocking System

intervals while the condenser is being rolled, the high-frequency resistance can be brought down to a low value and thus the condenser becomes properly available as a by-pass. The resistance-wire coils shown are 500 ohms each and they assist in stopping the high-frequency currents; they are also very useful in preventing accidental short circuits of the high-tension

batteries during experiments. They cause only a slight drop of voltage.

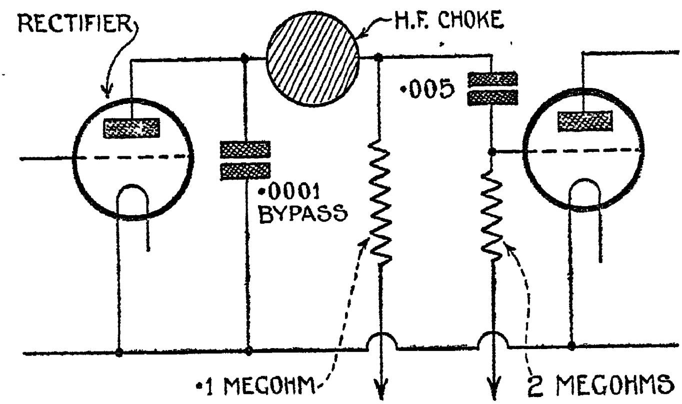


Fig. 34.—Stopping the H.F. from getting into the L.F.

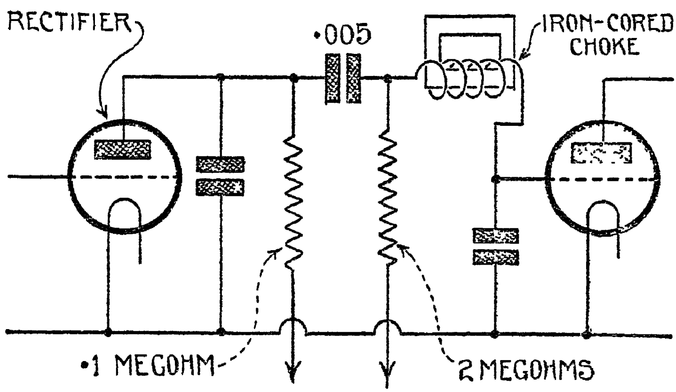


Fig. 35.—Marconi System of H.F. Stopping and Frequency Correction

I have emphasised the necessity of preventing the high-frequency carrying on into the low-frequency. This is very important, because any high-frequency

arriving at the loud speaker leads can easily induce back into the aerial. To obviate this I generally adopt the following plan. The rectifier valve and its plate circuit is electrostatically shielded (one usually shields the whole of the low-frequency amplifier at once), and then a high-frequency choke and by-pass condenser are inserted in the plate lead of the rectifier (Fig. 34). This method is not new, of course, but I have recently modified it to produce a new effect.

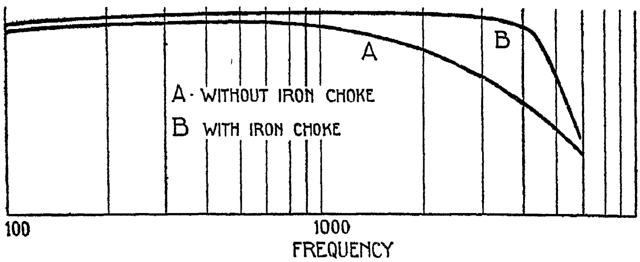


Fig. 36.—L.F. Characteristics with and without Iron Choke

Resistance-capacity-coupled amplifiers, if their amplification is stretched with high plate resistances, drop off in amplification in the higher speech frequencies. To overcome this defect I insert an iron-cored choke of considerable value, as shown in Fig 35; this in itself is made to replace the high-frequency choke. An additional shunt-condenser as shown, helps the by-pass effect and is also useful for low-frequency purposes as it controls the magnification of the higher notes.

The curves of Fig. 36 show the low-frequency

characteristics with and without the iron choke. It will be seen how the higher frequencies are maintained. This effect is similar to the magnetic-leakage effect in transformers, and the transformer-leakage effect suggested this solution of the falling-characteristic difficulty in the resistance-capacity amplifier. In addition to these choke and condenser arrangements I usually shunt the loud-speaker leads with a ·003-mfd. condenser still further to short circuit any high-frequency to the case.

If carefully made, it will be found that when using a tetrode receiver with a frame, an earth lead can be omitted, particularly on the shorter wave range. On the longer or Daventry ranges, however, it is sometimes an advantage.

It is always slightly safer to have an earth lead, as it definitely anchors the zero potentials, but I think that the necessity is less than with a neutralized circuit.

be controlled against oscillation by varying the filament current.

This low plate voltage point is a very interesting one and will no doubt be much used in these tetrode receivers where sharp tuning is required.

For those who already have a receiver consisting of, say, one reacting and rectifying valve and one or

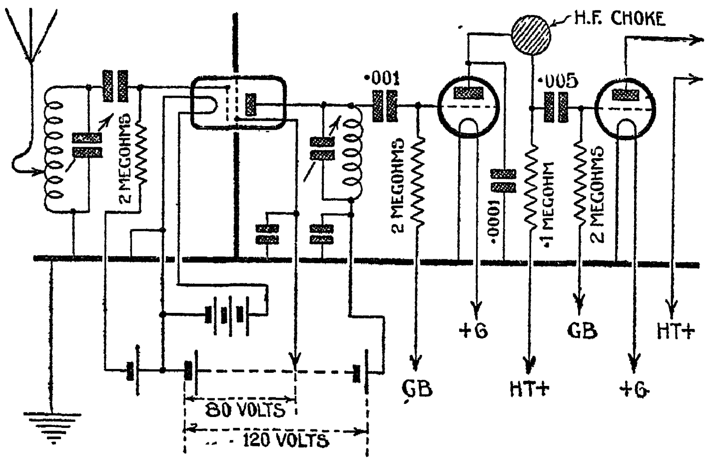


Fig. 38.—High Quality Circuit with Plate Bend Rectification

two low-frequency stages, the D.E.S. 625 valve will open out new fields without much additional expense and will enormously improve the tuning available.

Fig. 39 shows the circuit which should be placed in front of the existing receiver, and this can be connected up without any alteration to the existing gear. This arrangement, I find, works very smoothly in front of many receivers, particularly those with a

reacting rectifier and no H.F., and it greatly increases their range and tuning.

Some freak circuits which will interest experimenters I will describe later, as for the present it is desirable to keep to straightforward practice.

Fig. 40 shows the scheme of connections for two high-frequency stages, a grid leak rectifier, reaction and one

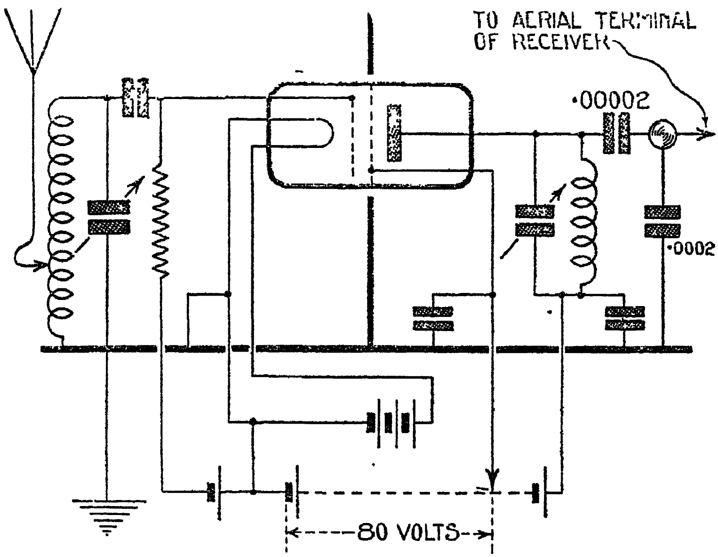


Fig. 39.—H.F. Adapter Unit for Improving Present Receivers

low-frequency stage—a very powerful combination with very fair tuning. With two low frequency stages and a 2-ft. square frame, this arrangement is nearly as good as the best super as regards sensitivity.

Fig. 41 shows a purity 4-valve arrangement without reaction, and this is suitable for all-station reception

on an aerial. The range and tuning are not so good as the circuit of Fig. 40, but it is cheaper to make, easier to handle and provides splendid quality. Its only real fault is that tuning is not quite what one would like, but this, I consider, is worth sacrificing for the high quality. Again, this set can be used with 20 volts on the plates of the H.F. valves with a big gain of tuning, but with some loss of quality owing to the sharp tuning. An additional L.F. magnification can easily be added to this to give increased volume on the weaker stations.

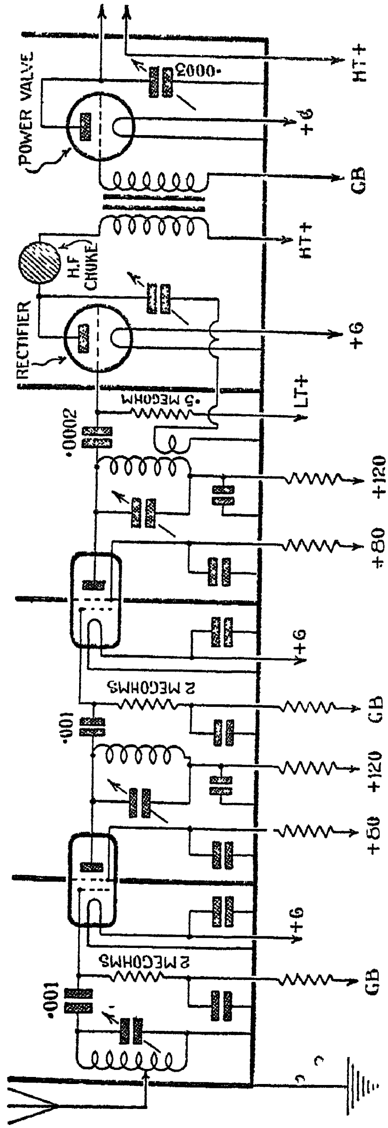
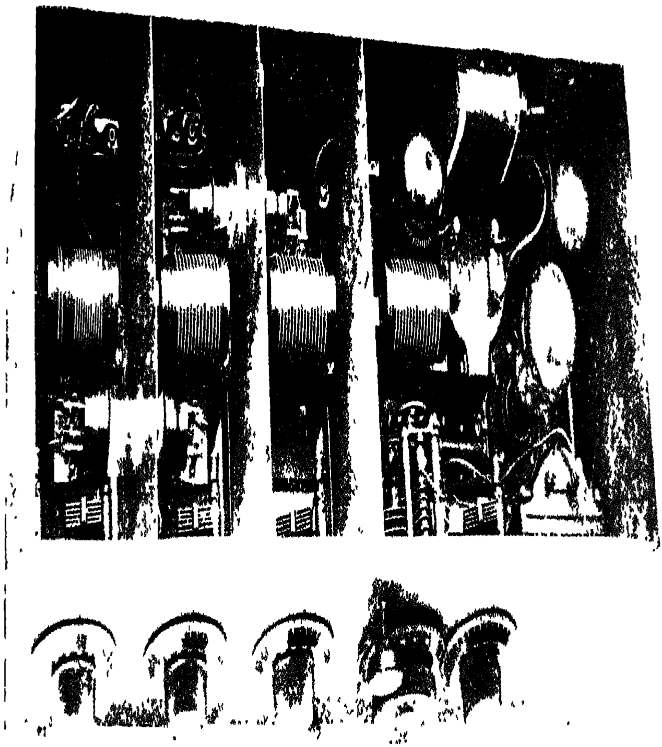


Fig. 40.—A 2 H.F. Combination similar to Fig. 37, but with one more H.F.



A short-wave (14-100 metre) amplifier consisting of 2 H.F., detector and 2 L.F. stages. Connections as in Fig. 53 (page 83).

Facing page 65.

Ganging the condensers is not difficult in these receivers, particularly when a frame is used. All that is necessary for success is that the tuning coil should have a small adjustment for inductance, and that vernier condensers be provided in parallel with each main tuning condenser. In chapter X the method of ganging a group of condensers is described.

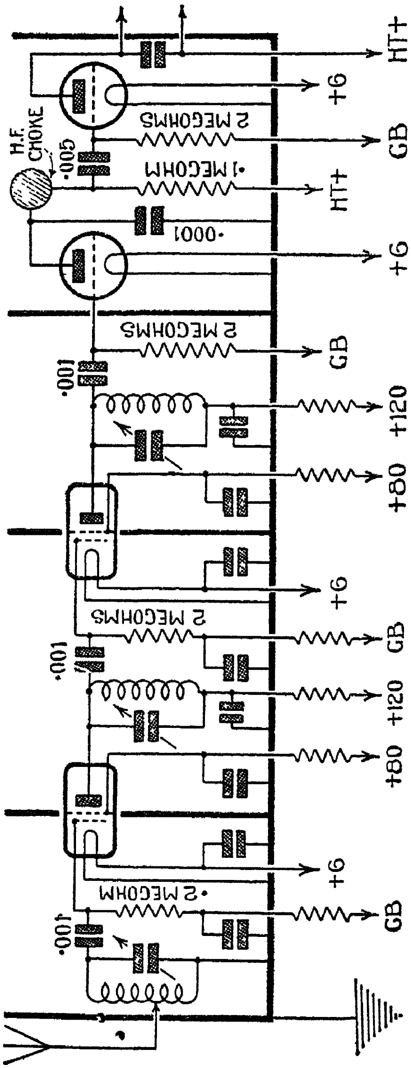


Fig. 41.—Pure Tone Long Range Set

Fig. 42 shows the connections of a 6-valve set using three tetrodes, a rectifier, one L.F. stage and one power valve.

Such a receiver with three H.F. tetrodes is almost

too powerful a combination for normal aerial use, for even when not used all out it is up to mush limit on a small frame. Actually with the filaments at full brilliancy and 80 and 120 volts on the O.G. and plate, respectively, valve hiss is a little too strong, and magnification should be reduced in any of the ways previously noted—if then a weak station, say in the daytime, is not of sufficient strength—the addition of an aerial is of advantage.

Strength and sensitivity will usually, however, be ample with these three H.F. valves even with a 1-ft. square frame.

I have not yet accurately determined the matter, but I imagine that the valve hiss is a little stronger in these valves than in triodes. The difference

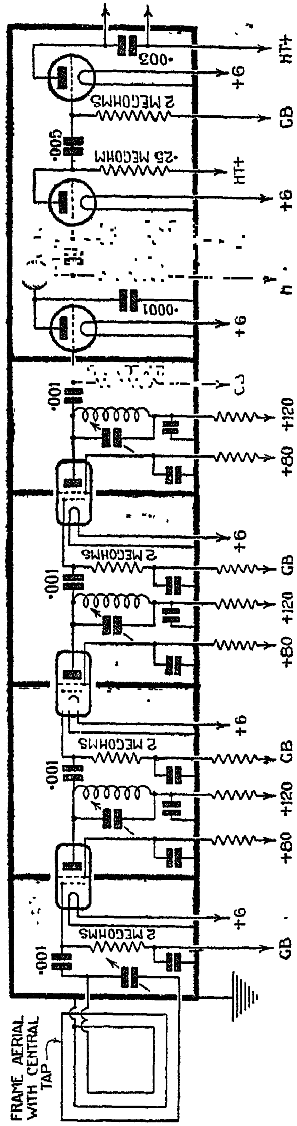


Fig. 42.—The Circuit of the Marconi 6-Valve Tetrode Sets (see Plate *facing* p. 48)

is, however, sufficiently small to make it a doubtful question.

Valve hiss tends to limit the minimum size of frame usable, otherwise there is no reason why more than a 3-in. frame should be used. In fact, some of the stronger continental stations with the 6-valve set are quite loud on the speaker with a 2-in. frame at night-time.

With the resistance-capacity-coupled sets, the quality is irreproachable, and I think it is hardly necessary to illustrate more than the 6-valve set with three high-frequency stages and one or two resistance-capacity-coupled low-frequency stages: as I cannot conceive the necessity of reaction or even L.F. transformer magnification, with three tetrodes in use.

With the 6-valve set—a picture of which is shown—every possible care is taken with regard to shielding. The dished base has an additional sheet of metal under it, a lid of metal covers the set and this makes good contact with the shielding by means of copper flex. Also, most of the leads are brought out in the American fashion, as a flex cord. Many of these details are not necessary if the frame is kept 18 in. or 2 ft. away from the set, but this is not always convenient, particularly in a commercial set.

Long wave coils for all these sets should not be too efficient, because four circuits in cascade tend to muffle signals and the magnification is more than is required for all the European long wave stations.

High loss should, however, not be carried too far, otherwise the various long waves will not be easily separated.

Again, condenser ganging is comparatively easy with these sets, but necessarily adds considerably to the cost of the receiver.

The ganging is complicated by the two ranges of wave length also, as different zero capacities have to be considered with the two ranges of coils.

CHAPTER VII

High Quality

The tetrode lends itself to the production of high-quality reception because it provides such great high-frequency magnification, which makes it possible to use more accurate but less sensitive methods of low-frequency amplification.

An anode-bend rectifier driving a power valve directly through a resistance-capacity-coupling is not likely to give much distortion, and two stages of tetrode amplification in front of this will give high sensitivity with a fair aerial. One further stage of resistance-capacity-coupling is almost too noisy and it is, in my opinion, more than the tuning of three circuits will stand unless a lower voltage is used on the tetrode. Two stages of low-frequency amplification and a plate-bend rectifier can be made with a very level curve from 50 cycles to 6,000 cycles and three stages of tetrode amplification, using a 1-ft. square frame aerial, added to this are more than sufficient to load the power valve up on all but the feeblest signals. In such a case valve or other mush will be the limiting factor and not weakness.

Very careful separation of the high frequency from

the low frequency is necessary in these receivers, in order to obtain good quality, and elsewhere I have indicated how this can best be done. A certain element of quality is unfortunately lost in the high-frequency tuning, particularly on the longer wave lengths, because there is a limit to the number of tuning circuits it is possible to use. My usual method of overcoming this difficulty when strength will permit is slightly to mistune the various condensers towards a shorter wave in the first condenser, a longer wave in the second condenser, and so on; a crisper tone on distant stations will result. This effect is very noticeable on the Daventry range.

Ganged condensers—as they never quite tune—are prone to give better quality than independently controlled condensers, but of course weaker signals result.

Resistance-capacity-coupling and tuning both tend to cut down the higher frequencies, and this, though perhaps not harmful on music, tends to spoil the intelligibility of speech. For this reason I have taken precautions in the Marconi receivers to maintain the higher tones in the low-frequency amplifier by means of a leakage choke. I think it might almost be wise to increase the tones over 3,000 cycles above normal on account of the fact that most loud-speakers fall off above these frequencies, and this would tend to balance the loss of higher frequencies on the tuning. I found it an advantage to have the lowest frequencies

below 50 cycles well cut down by using small coupling condensers, as otherwise high-resistance batteries tend to cause oscillation.

The following values used in good resistance amplifiers will be useful:

Case 1.—In this example the anode-bend detector

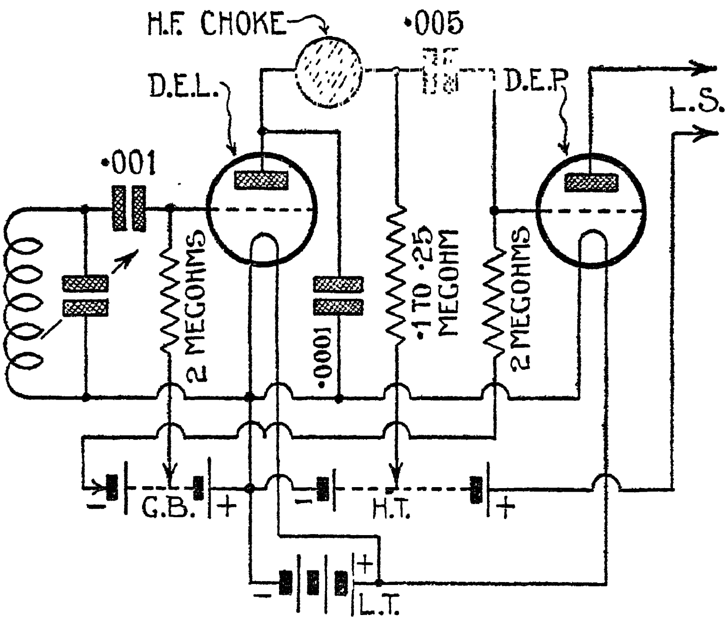


Fig. 43.—Showing Quantities Required for R.C. Coupled Detector and Power Valve

is intended to run the power valve directly, and a detector of medium magnification value should be chosen. As detector valve, a D.E.L. with a magnification factor of 15 is suitable, but when greater sensitivity is required and the power valve is not required

to run up to full strength, a D.E.H. type with a magnification of 40 will be found satisfactory and more sensitive.

I prefer to keep the plate resistance in this rectifier down to ·1 megohm because of tone effects—and a capacity of ·0001 mfd. for the by-pass condenser should not be exceeded.

Coupling condensers should be kept small and be of high insulation quality, a capacity of ·005 mfd. is ample if 2-megohm grid leaks are used.

The D.E.L. type rectifier will fully load the power valve unless a power valve of very low magnification factor is chosen for the last stage.

The only fault of the direct drive from the rectifier is that if a station is only weakly modulated, full signals cannot easily be obtained, as the carrier wave chokes up the detector, but all modern stations are sufficiently well modulated.

Fig. 43 shows the complete arrangement.

Case 2.—In this case the first valve can always be of high magnification value, such as the D.E.H. type. The second valve I prefer to be of medium magnification value, and the last, of course, a power type—the different constants being as shown in Fig. 44. I have illustrated the H.F. choke arrangement, which gives satisfactory results, in both Figs. 43 and 44. The object of this is to block out any H.F. from the pure L.F. stages—where it may possibly decrease the volume obtainable and also give reaction effects.

With the H.T. in good condition, both these circuits will give irreproachable quality, but of course the higher the H.T. value the better will be the volume without blasting. Grid bias may be found experi-

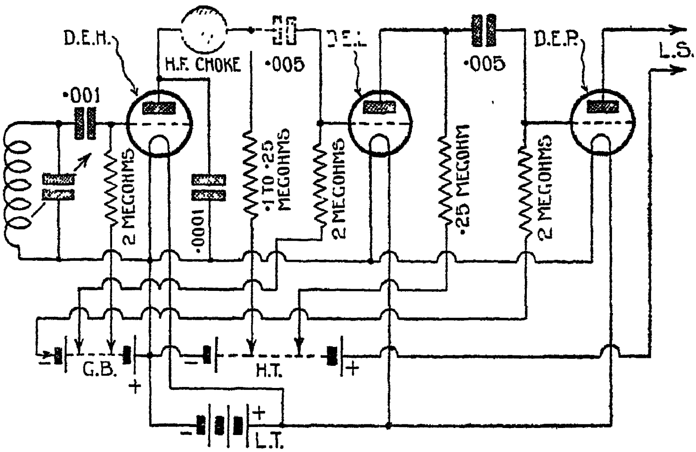


Fig. 44.—Showing Quantities Required for R.C. Coupled Detector and 2 L.F. Stages

mentally, the rough rule being $\frac{\text{H.T.}}{2 \times \text{M.}}$ for amplifiers and $\frac{\text{H.T.}}{\text{M.}}$ for the rectifier; the latter, however, can quite easily be set experimentally on weak signals.

Such sets as these are worth a good loud-speaker.

CHAPTER VIII

Some Possible Circuits and the Super Heterodyne

Almost all of the straight and "super" circuits that are used with ordinary valves, are possible with the tetrode. Thus the simple reaction circuit of Fig. 45

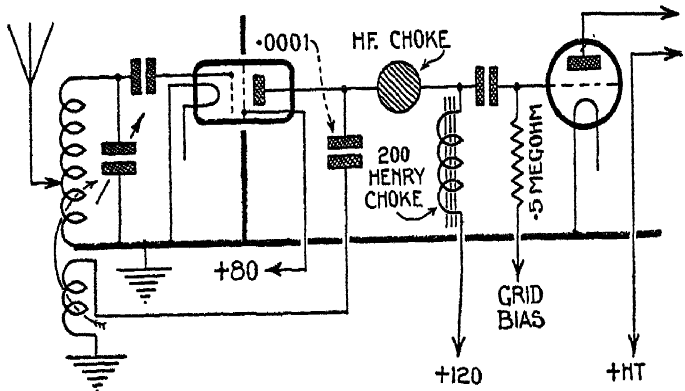


Fig. 45.—Simple Reaction Circuit with Tetrode

can be used, but it is doubtful whether its advantages are very great over a similar circuit used with an ordinary valve. It will be noted that I indicate a choke transformation to the second valve, and this choke should be over 100 henries in order to secure good reproduction of the bass.

In Fig. 46 a tuned-anode circuit is indicated and this

can be reflexed as shown, so that there is one high-frequency, one detector, one low-frequency and one power stage with only three valves.

Crystal rectification can be used if desired as shown in Fig. 47 and in this reaction will have to be applied

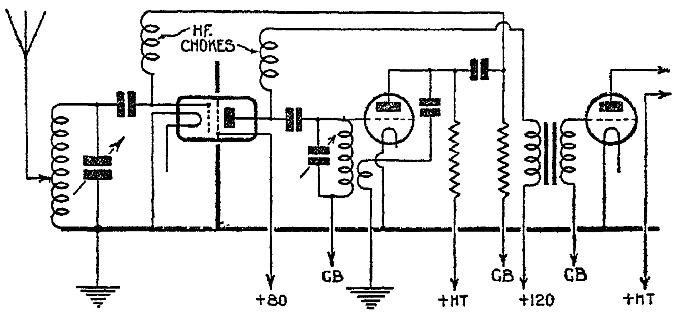


Fig. 46.—Reflex Tuned Anode Circuit

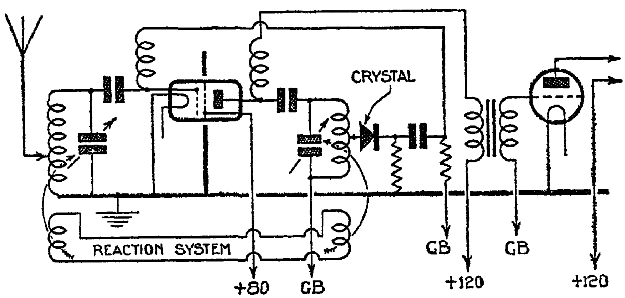


Fig. 47.—Reflex Circuit with Crystal Rectifier

in some way as shown, using the high-frequency valve to get the reaction. This circuit can, of course, be reflexed.

I should be loath to attempt double reflexing, that is with two high-frequency valves and two low-

frequency valves, but one high-frequency valve could easily be added in front of the circuits, Figs. 46 and 47.

If a straight circuit using all tetrodes with the exception of the power valve is required, a suitable circuit is shown by Fig. 48, where either plate-bend or

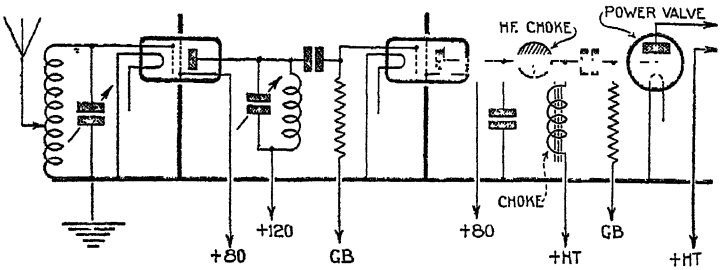


Fig. 48.—Tetrode used as Rectifier

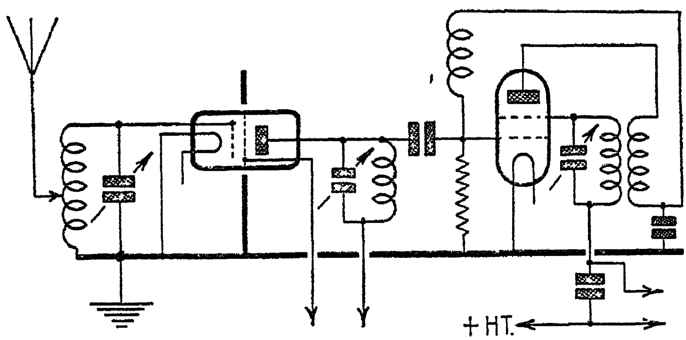


Fig. 49.—First Valve H.F., Second Valve H.F., Detector and L.F.

grid rectification can be used. Some trick circuits of the type shown by Fig 49 are possible where the first valve is used as a shielded tube, and the second valve as a high-frequency stage followed by detection and low-frequency in the same valve.

Resistance amplification can be carried out down to about 200 metres with these valves, providing the plate resistance values are kept low, say 10,000 to 20,000 ohms, and the necessary additional plate volts (from 10–20 volts) added to make up for D.C. losses. Larger resistances than these are not necessary because the capacity of the valve is already of very low impedance. A cascade resistance amplifier with a magnification of 1,000 is indicated in Fig. 50. The resistances can easily be wound of fine resistance wire as a spiral on a small tube.

Choke amplification of high frequency is also possible but resonance effects are liable to be obtained unless the chokes are constructed for limited ranges of wave-lengths; a choke shunted with a resistance is a very good compromise.

Super-heterodyne circuits should be simple with these valves. The first high-frequency stage nearly always used in supers will be a great improvement on that obtained with the old triodes, and it should be possible to do with only one stage of intermediate frequency on account of the gain per stage in H.F. and I.F. Even with two I.F. stages the intermediate steps would be much easier to handle providing the necessary shielding precautions are taken, but, of course, the standard transformers for intermediate frequency will not be correct; plain tuned chokes will probably be the best arrangement, and as the valve impedances for best working are high, high inductance

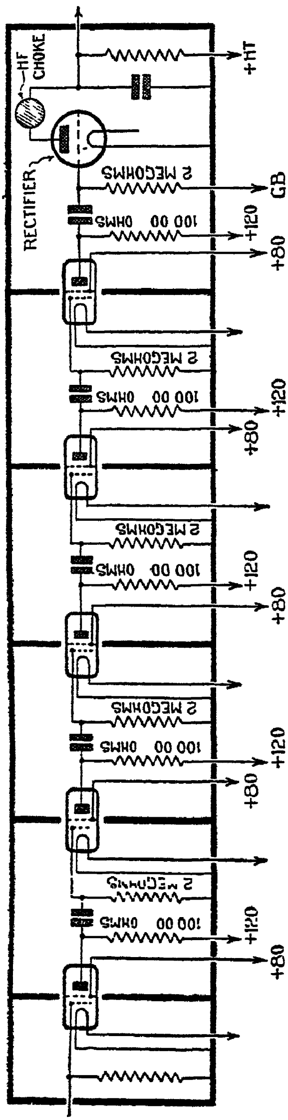


Fig. 50.—H.F. Resistance Amplifier with Tetrode

and small condenser values will be best.

For those who are content to do without high-frequency amplification in their supers, the use of the tetrodes in the intermediate stages will be found to give a great deal more available magnification without reaction trouble.

An ordinary triode oscillating as a harmonic and receiving from the frame, could put the rectified current into two tetrodes in cascade with a magnification of 80 each. After rectification and low-frequency magnification this would give ample volume for frame working. But what will the advantage be over straight high-frequency magnification? None that I can see at the moment. Where I think the tetrode will be of use in super-heterodyne work

will be for very short waves, and for enabling us to build the super tuning circuits for broadcast reception, receivers which will give very nearly ideal tuning.

The tetrode makes easily possible an infradyne circuit as the construction of the necessary 80- or 100-metre amplifier will be quite simple, but the details of such an arrangement which I could give here would not be of a very practical nature and at present I see no particular point in carrying out work in this direction.

CHAPTER IX

Short-wave Receivers.

THE reception of short waves, both telegraph and telephone, is a subject of very vital interest nowadays.

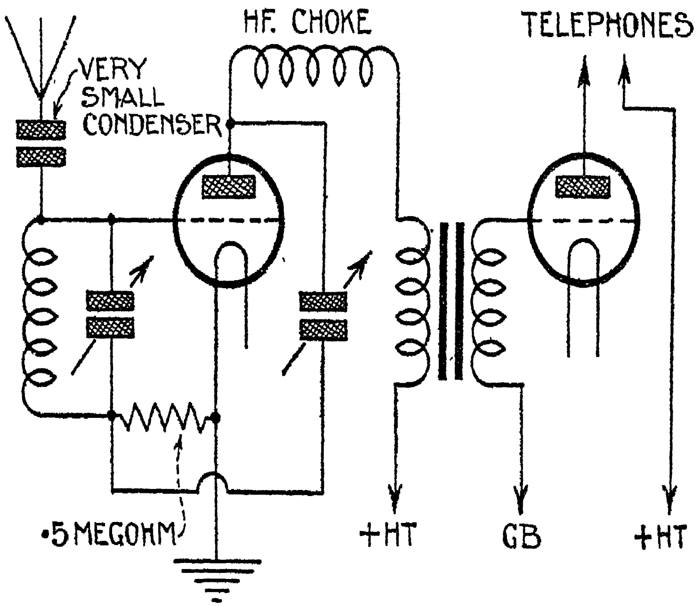


Fig. 51.—Simple Circuit containing Self-heterodyne Valve and L.F. Amplifier

For telegraphic purposes, that is the reception of morse signals, no better circuit is in use than a simple self-heterodyne valve with a low-frequency amplifier after this, such as is illustrated in Fig 51. The

reception of telegraphy in the oscillating condition is linear, that is the efficiency remains constant down to the weakest signals so that low-frequency magnification seems all that is necessary. Some practical points, however, enter into the subject, which are rather important.

A self-heterodyne valve usually has the aerial in part of its oscillating system and an aerial is liable to vary, due to wind, etc., so that the heterodyne note may be unsteady on occasions. Also self-heterodyning is not too nice on short waves because the radiation is even more severe than on broadcast wavelengths, and the effect of this may be felt by other receivers at quite considerable distances.

Then again a curious phenomenon occurs, particularly with waves under 30 metres. When the receiver is oscillating the radiation given by it may be picked up by objects in the vicinity such as by metal stove-pipes or mast stays, and if these are capable of being vibrated, and they have bad contacts in them, the result is a production of home-made atmospherics, which are very annoying. Even the act of touching a metal object somewhere in the room very often causes a click in the receiver.

Some recent work by my co-worker, Captain Tremellen, has indicated that an advantage is obtained by using the tetrode in practical working down to wavelengths as low as 12 metres. Tuned-plate circuits are possible and magnification is quite marked,

although it falls off considerably as the wavelength is decreased.

Fig. 52 shows the connections for a short-wave receiver with one tetrode and the method of searching and tuning is quite simple. First of all the aerial is capacity connected by a very minute condenser to the tuned grid coil of the detector. The tetrode can be left alight but the tuned anode coil of the tetrode

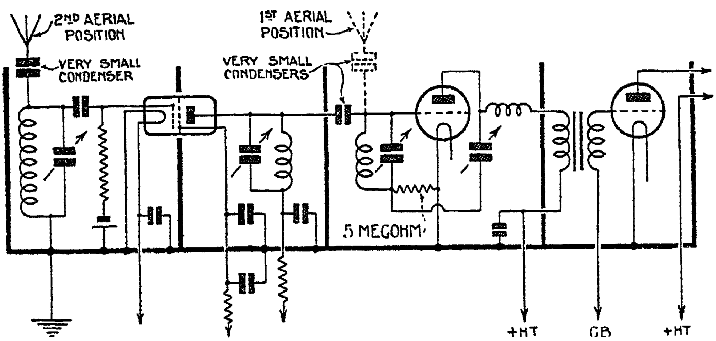


Fig. 52.—A Short-wave Receiver with One Stage of H.F. Amplification

should be quite out of tune. The tuning condenser of the detector is now turned until the required carrier wave is heard, a best setting of the reaction condenser being also obtained.

The tuned anode condenser of the tetrode is then turned until a click or sharp change of heterodyne note is heard. Then this process is repeated with the tuned grid of the tetrode and finally the aerial is shifted over and capacity connected to the tetrode grid coil and a slight retuning made.

A little experience will soon enable the three condensers to be kept in step over the range without repeating the initial process. There is probably no difficulty in ganging because the tuning of all but the detector condenser is quite broad.

Amplified signals will now be obtained, although for morse reception the advantage of amplifying in this way is not very great. There will, however, be no fear of serious radiation or aerial-sway effect.

In making such a receiver, care must be taken to block at the bottoms of the coils very carefully, the condensers being connected very close to the lead-

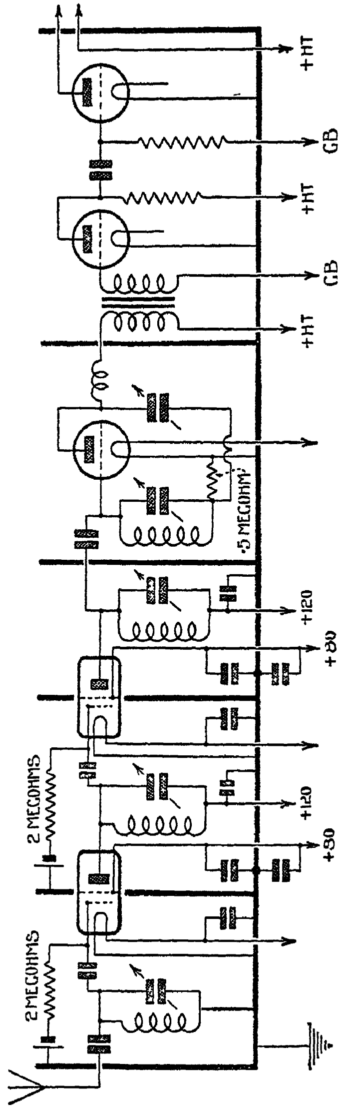


Fig. 53.—Two-stage H.F. Short-wave Receiver, Range of Wave-length 12 Metres Upward (see Plate *facing* p. 65)

ing-out points. Double blocking of the outer grid connection is an advantage. Separate grid biases for the high-frequency obviate the necessity of having to block the grid leaks.

On telephony reception the addition of this valve will be found a very big advantage, for here the efficiency of rectification is not constant but falls off with amplitude fall, so that high-frequency amplification is of great advantage. A two-stage high frequency five-valve short-wave receiver circuit is shown by Fig 53 and also a photograph of this receiver which has various ranges of plug-in coils.

A careful choice of tuning condensers is required as these must be small with small zero capacities and with a non-metallic gearing if possible ; at least, there must not be any metal teeth in the gearing, as this construction tends to the production of noises when oscillating.

I have obtained some extraordinary reception on this receiver, particularly when using the condition of "zero beat," which Captain Tremellen has discovered practically eliminates the rapid fading on short waves. This condition is fairly easy to attain, because of the stability of oscillation and non-existence of aerial-sway action.

CHAPTER X

Single-handed Control

AT the present time if we use straight high-frequency amplification methods we have no alternatives in simplifying the operation of a receiver except some form of ganging. Either condensers, or inductances, or both may be ganged.

This practice necessarily requires a degree of accuracy which is not so essential without the ganging, and therefore it is considerably cheaper to make an unganged receiver than to make one that is ganged.

For serious listeners there is not a great disadvantage in using a separately controlled receiver, providing it is properly calibrated, as I have proved with the Marconi Straight Eight. Wave lengths are published and one soon gets to know the stations worth looking for. There is no doubt, however, that single control is a fascinating subject and if it can be done well is of considerable advantage. At the present time, however, it is not possible to design a receiver at a reasonable cost with single control which will be as efficient as one which has multi-control.

The following account of some highly successful experiments in ganging the tetrode circuits for both ranges of wave length will be useful to the experimenter.

Three ·00025-mfd. condensers of the square-law type were linked together accurately in phase, that is, their maxima occurred together. Suitable gearing was provided to drive the combination (this is essential as such a cascade series gives fine tuning). In parallel with each condenser was a vernier condenser with a maximum capacity of ·0004 mfd.

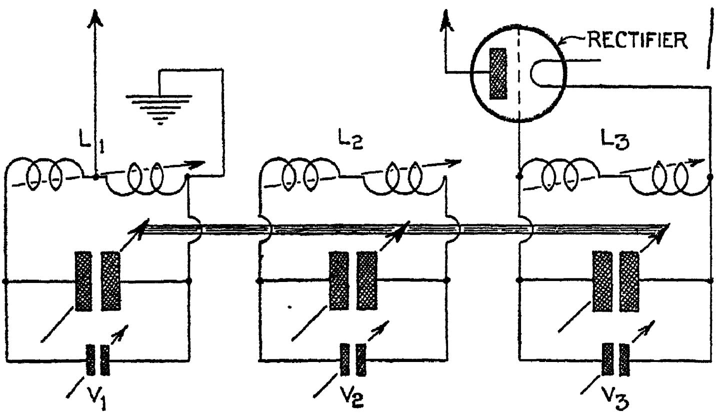


Fig. 54.—Single-handed Control (a Successful Circuit)

The inductances attached to each condenser were of the variometer pattern astatic coils (see Fig 54), so that a small change of value of inductance could be made in each. The aerial was connected to a tap position and with a wavemeter the whole circuit was tuned up with the three condensers at maximum and the vernier condensers at zero, by alteration of the inductances. Then the three main condensers were turned to zero and the circuit again tuned by adjusting the vernier condensers to the correct value. It

was found that if the aerial vernier was set to a small positive value, the second condenser had to be brought to a much larger value, and the third condenser to an intermediate value, indicating that the aerial capacity was the largest of the zero capacities, the rectifier capacity the next, and that the zero capacity of the centre winding was comparatively small.

Now the main condensers were again brought to a maximum and the three circuits again tuned by altering the variometers. Again the process of reduction of the main tuning to zero was carried out and the verniers slightly altered. This alteration was, however, slight. Leaving the verniers fixed at these positions, which were carefully marked, it was found that the main tuning was effectively ganged and that at any position very little adjustment of the verniers was necessary. The tuning coils were carefully sealed so that no change of inductance could now take place. The markings of the verniers were called the "short-range zeros."

The long-wave set of coils were now switched on and the process repeated, three new zeros being necessary, and these were accordingly marked. After this the verniers could be used on either range for fine tuning, but for ordinary work they were left at the appropriate zeros.

The larger the number of circuits, the easier it is to gang, providing the necessary gang of condensers can be made, because each individual tuning need not be so good.

APPENDIX

The relation between I_A, V_A and V_g in a valve is usually expressed as a graph or characteristic because it is too complex a relation in practice to represent otherwise.

Langmuir showed that ideally these quantities could be put into the form

$$I_A = k\left[V_g + \frac{V_A}{M}\right]^{\frac{3}{2}}$$

but a little later Latour pointed out that if one was content to work over small ranges of the characteristic the formula

$$I = K\left[V_g + \frac{V_A}{M}\right] + A$$

would represent the action of the valve.

In this formula K becomes the mutual conductivity and, as we have seen, this is equal to $\frac{M_A}{K_A}$

Obviously for small changes

$$d\,I = K\left[d\,V_g + \frac{d\,V_A}{M}\right]$$

Suppose we put a resistance R in series with the valve-plate circuit and apply to the combination a battery volts V_0. Then the same I flows through both the valve and the resistance R, and we have by ohms law

$$I = \frac{V_0 - V_A}{R}$$

or for small changes $d\,I = -\frac{d\,V_A}{R}$

Equating the two values of dI we get

$$K\left[dV_g + \frac{dV_A}{M}\right] = -\frac{dV_A}{R}$$

which gives us $\frac{dV_A}{dV_g}\left[\text{the amplification}\right] = \dfrac{K}{\frac{K}{M} + \frac{1}{R}}$

but $\frac{K}{M} = \dfrac{\frac{M}{R_A}}{M} = \frac{1}{R_A}$

so that the amplification is equal to 1 which agrees with the formula obtained by making the assumption that a voltage $M\,dV_g$ was split up between the resistances R_A and R_X.

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